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Hybrid operation of wind-diesel-fuel cell remote area power supply system

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Abstract

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Hybrid Operation of Wind-Diesel-Fuel Cell Remote Area Power Supply System

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***Abstract*—Due to the uncertainties associated with wind profiles, the load side voltage and frequency control of a wind dominated Remote Area Power Supply (RAPS) system is a challenging task. The performance of such a wind dominated hybrid RAPS system consisting of a diesel generator, fuel cell system, dump load and mains load is investigated in this paper. Integrating a fuel cell into the RAPS system enables the diesel usage to be kept at its minium level while avoiding operation of the diesel generator at low load factor. The diesel generator is used to provide the reactive power requirement of the system throughout the operation and to provide active power whenever necessary. The excess power that arises during over generation scenarios such as high wind and low load conditions are handled through the dump load. To achieve acceptable voltage and frequency regulation, individual controllers have been designed and developed for each system component. In addition, a strategy for control coordination has been established among all the system modules. The entire system was modelled using SimpowerSystem toolbox in MATLAB and the suitability of the system is investigated in relation to its voltage and frequency regulation capability under changing wind and variable load conditions.**

***Index Terms*—Remote Area Power Systems, Doubly Fed Induction Generator, Diesel Generator, Fuel Cell and Dump load**

I. INTRODUCTION

REMOTE Area Power Supply (RAPS) schemes are becoming popular among rural and regional communities. With the penetration of renewable energy technologies into the electricity market, standalone power systems which are entirely based on diesel generation systems are becoming less attractive [1]. Instead, hybrid power systems consisting of one or more renewable energy sources integrated with conventional generation methods, such as diesel power, are identified as a promising solution to supply power to the rural communities [2]. The autonomy permitted by such schemes is still limited due to the dependency on fossil fuels. In this regard, the usage of the diesel generation can be minimised by increasing the renewable energy proportions in a hybrid RAPS system.

Depending on the availability of energy resources, a suitable generation mix can be used to form a hybrid RAPS system. Among all the renewable energy options, wind energy technology is identified as the fastest growing renewable energy technology [3]. However, the random variation of wind profiles leads to power fluctuations which causes unexpected voltage and frequency excursions especially in a situation where power is generated in standalone mode of operation. Rapid and flexible control of other means of generation is necessary to balance the wind power generation with load demand. In this regard, diesel power can be considered as one of the best options due to its reliability of supplying power and simplicity of operation [4]. Also, it can provide both the inertial and reactive power support to the system thus ensuring better frequency and voltage regulation. However, the operation of a diesel generator at all times is not desirable due to the operational constraints and cost, environmental concerns, etc. [5]. It generates power during low wind penetration time periods (ie. Wind-Diesel (WD) mode of operation) provided that the generation-demand mismatch is above the minimum permissible loading condition of the diesel generator. During high wind penetration periods (ie. Wind Only (WO) mode of operation), an Energy Storage System (ESS) is an attractive solution to maintain system power balance [6]. Alternatively, a fuel cell system can be integrated into the RAPS system which offers many advantages when compared to alternative sources [7], [8]. These include but not limited to low or no emissions, high energy conversion efficiencies compared to internal combustion engines, and low noise and vibrations. However, the economic feasibility is still a major subject of interest. A dump load is a common component in a RAPS system which absorbs excess energy available in the system. In a practical RAPS system, a dump load can be a water heater system or an electrolyser which can be used to produce hydrogen for the fuel cell cell system.

The relevant research work similar to the work presented in this paper include the operation of a grid connected DFIG based wind turbine with a fuel cell [8]. The parallel operation of an induction generator based wind turbine, diesel generator and fuel cell is discussed in [9]. The power quality issues associated with grid connected wind turbine-fuel cell system is discussed in [10]. The small signal model of wind-diesel-fuel cell hybrid power system is presented in [1]. Based on extensive literature review, it has been noted that there is no detailed model covering hybrid RAPS systems containing DFIG as the main source of energy together with diesel generator, fuel cell system and dump load.

The hybrid RAPS system considered in this paper consists of a DFIG (main generator), diesel generator system, dump load and its controller, fuel cell system and mains load as shown in Fig. 1. The power flow of the system is coordinated by employing the various system modules with a view to minimise the active and reactive power imbalance associated

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with the system. In this regard, the DFIG, diesel generator, fuel cell and dump load, together with their controls are closely investigated. The simulation model consists of high order nonlinear models of the system modules which exhibit relatively more accurate system dynamics.

The paper is organised as follows. The control coordination strategies adopted to manage the power flow among the different system components are discussed in Section II. Section III discusses the control methodologies adopted for the wind turbine generator, diesel generator system, fuel cell and dump load. The simulated results demonstrating the behaviour of the proposed RAPS system under variable load and wind conditions are discussed in Section IV. Conclusions are given in Section V.

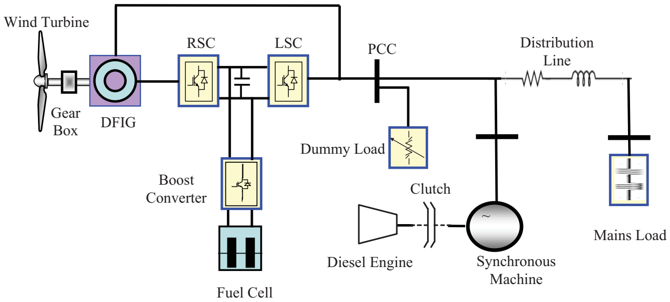

Fig. 1. Proposed hybrid RAPS system with fuel cell and diesel generation

II. CONTROL COORDINATION OF RAPS SYSTEM FOR DETAILED MODEL ANALYSIS

In a standalone RAPS system, the voltage and frequency are the major aspects to be controlled. In this regard, the active and reactive power imbalance of the system should be kept at a minimum level. In the proposed RAPS system, the DFIG and diesel generators are identified as the main reactive power sources. However, the reactive power support from DFIG is not sufficient all the time and hence it is designed to compensate its mangnetising reactive power component or no-load component (ie. unity power factor operation). More information regarding the modelling of the DFIG reactive power control is discussed in Section II. The reactive power demand of the system is entirely supplied by the diesel generator. The active power flow of the system is formulated through a control coordination strategy among four components; DFIG, diesel generator, fuel cell system and dump load, to satisfy the active power balance of the system which is given by (1).

$$P_w + P_{de} + P_{fc} \quad = \quad P_L + P_d \tag{1}$$

where,
P_w - wind power, P_{de} - diesel power, P_{fc} - fuel cell power, P_d - dump power and P_L - load demand.

A simplified schematic of the control coordination logic associated with the proposed RAPS system is shown in Fig. 2. It illustrates the decision making process associated with active power sharing among the different system modules employed to minimise the active power imbalance of the system. The details of the proposed control coordination strategy depicted in Fig. 2 is as follows. If the power output of the DFIG, P_w, is greater than the load power demand, P_L, the dump load absorbs the additional power (ie. $P_w - P_L$). If this excess power is greater than the maximum capacity of the dump load (ie. $(P_d)_{max}$), then the wind turbine pitch regulation is activated to control the excess wind power. Furthermore, it is assumed that wind power, P_w, diesel power, P_{de}, and fuel cell power, P_{fc}, are sufficient to satisfy the load demand at all times.

If the power output of the DFIG (ie. P_w) is smaller than the load demand (ie. P_L), two options are available and the decision making depends on the magnitude of ΔP_{wL}. If ΔP_{wL} is less than 30% of the synchronous generator capacity, the fuel cell system has to provide all the required power, P_{fc}, along with the DFIG. Otherwise, the synchronous generator should be able to provide the required power.

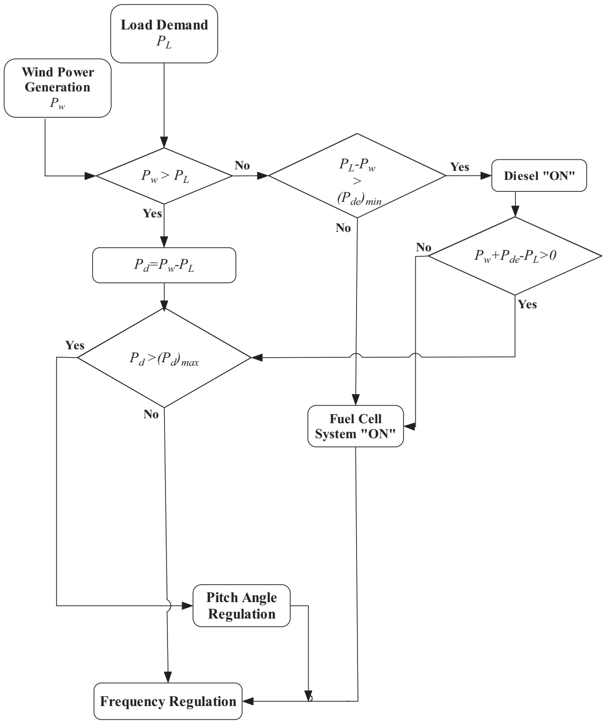

Fig. 2. Instantaneous power flow control of the proposed RAPS system

III. CONTROL STRATEGIES ADOPTED FOR INDIVIDUAL SYSTEM COMPONENT

In addition to the control coordination methodology, development of individual control strategies for each system component is vital to regulate the AC voltage and frequency within acceptable limits. In this paper, the highest capacity of the system is represented by DFIG followed by the diesel generator and fuel cell system respectively. The DFIG and diesel generator control have been developed to regulate the voltage and frequency. The fuel cell system and dump load controls are developed considering the power flow of the system. More information regarding the modelling of the individual controllers is given in following sub sections.

A. DFIG and Its Associated Control

The RSC is used to control the load side voltage and frequency while Line Side Converter (LSC) is used to control the DC link voltage of the back-to-back converter system. The methodologies suggested in [3] were used to model the controllers for RSC and LSC.

The frequency regulation of the system through the DFIG is achieved by ensuring the indirect stator flux oriented mode of operation of the RSC. This condition can be ensured by implementing the condition given by (2). To provide better voltage support, the DFIG is modified to compensate its no load reactive power. This can be achieved by ensuring the condition given in (3). The entire control structure of the RSC is shown in Fig. 3. The LSC control is conventional as discussed in [11].

$$i_{qr} = -\frac{L_s}{L_m} i_{qs} \tag{2}$$

$$i_{dr} = \frac{V_s}{\omega_s L_m} \tag{3}$$

where,
V_s - system voltage, i_{dr} - rotor d-axis component, i_{qr}, i_{qs} - rotor and stator q-axis current respectively, L_s, L_m - stator inductance and magnetising inductance respectively.

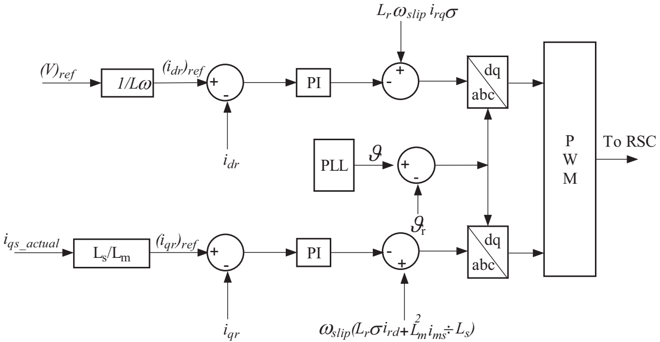

Fig. 3. Rotor side converter control

B. Diesel Engine and Synchronous Generator Controls

In this paper, the Synchronous Machine (SM) is designed to operate either as a generator or condenser depending on the wind and loading condition of the system. The two operating modes of the synchronous machine are controlled using a clutch model as discussed in [12]. The clutch model is responsible in transferring the torque generated by the diesel engine. The state transition of the SM (ie. synchronous condenser to generator mode of operation) needs to fulfil the following requirements;

- The power deficit of wind and demand, $P_w - P_L$ should be greater than $30\% \times (P_{de}$ rated capacity).
- After the cracking process of diesel engine, the speed deviation of diesel engine and synchronous machine should be less than $\pm 1 \times 10^{-4}$ pu.

When the above criterions are fulfilled, the clutch moves to "ON" state thus transferring torque to the SM. The total torque transferred to the SM can be expressed using (4). Also an additional PI controller is integrated into the diesel engine model to provide better power sharing among the diesel and wind generators. The generation of the clutch signal and the diesel engine model are shown in Figs. 4 and 5 respectively.

IEEE type 1 voltage regulator and exciter system is used for the diesel generator. Further details of the exciter model can be found in [12].

The estimation of the size of a diesel generator for a renewable energy based power system is still a major issue [13], [14] and is beyond the scope of this paper. Therefore it is assumed that the synchronous generator is sufficient to provide 30% of the rated power requirement of the rated capacity of the entire system.

$$T_c = \frac{H_s T_d + H_d T_s}{H_s + H_d} \tag{4}$$

where,
T_c - equivalent torque transmitted to SM when clutch signal=1, H_s and H_d - inertia constants of SM and diesel engine respectively, T_s, T_d - torques of SM and DE ω_d - diesel engine speed.

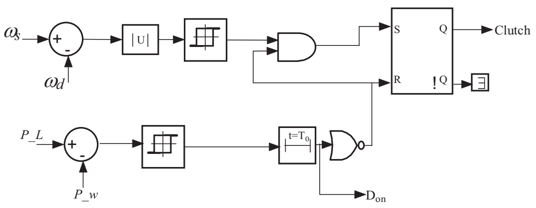

Fig. 4. Generation of clutch signal

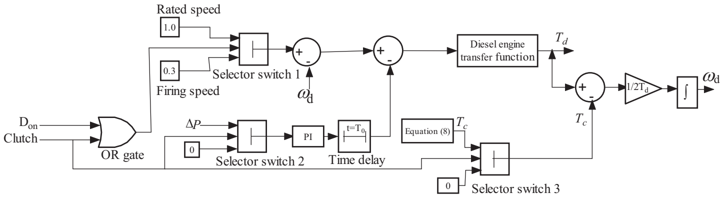

Fig. 5. The proposed model of the diesel engine

C. Fuel Cell System

In this paper, a Silicon Oxide Fuel cell (SOFC) is integrated into the DC link of the DFIG system as it is recommended for high power applications. The modelling aspects of a fuel cell proposed in [15] is used as a reference in this paper. The simulated model of the SOFC system is shown in Fig. 6. The fuel cell model mainly consists of two components.

- I :Fuel processor- Converts the fuel into hydrogen and byproduct gases.

- II :Power section (fuel cell)- This section generates the current and cells are connected in series to generate high power.

Molar flow rates of hydrogen and oxygen are used to calculate the partial pressures, P_{H_2O}, P_{H_2} and P_{O_2}. These partial pressures are used to calculate the reversible voltage or Nernst's voltage of the fuel cell. Also, the three losses associated with the fuel cell are incorporated in the model as shown in Fig. 6. For the sake of simplicity, a single boost converter is used to interface the fuel cell system into the DC link which is shown in Fig. 7.

The generation of switching signal for the boost converter is shown in Fig . 8. It measures the demand generation mismatch, P_L-P_w, and generates the reference current of the fuel cell, $(i_{fc})_{ref}$ only if the demand generation mismatch is smaller than the 30% of the diesel generator rating. This reference current is then compared with its actual current, i_{fc}, to generate the switching signal for the boost converter.

The estimation of the size of a fuel cell system is extremely site specific. In this paper, the sizing of the fuel cell is assumed to provide 15% of the rated system demand(ie. 0.15 pu).

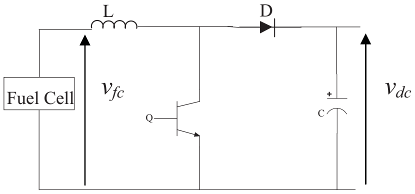

Fig. 7. Boost converter for the fuel cell

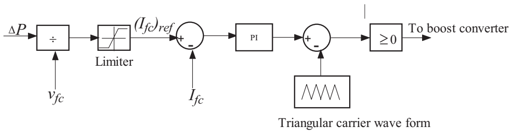

Fig. 8. Switching signal for boost converter of the fuel cell

D. Dump Load Control

The dump load of the system is coordinated with the fuel cell system and diesel generator to maintain the power balance of the system. For simulation purposes, this could be represented by a series of resistors which are connected across switches. The resistors operate at zero crossings of the system voltage to ensure minimum impact on the system voltage quality. The operation of the dump load is limited to when there is additional power available in the system.

IV. SIMULATION RESULTS

The entire RAPS system was simulated under variable wind and load conditions. In this regard, active power sharing among various system components was observed. The AC voltage, frequency at Point of Common Coupling (PCC) and DC link stability of the DFIG are also examined. The performance of the fuel cell is also observed in relation to its DC voltage and current and the partial pressures of oxygen and hydrogen.

Fig. 9 shows the system response and Fig. 10 illustrates the power sharing among different system components. The wind condition under which the system has been simulated is shown in Fig. 9-(a). It can be seen that the wind velocity is set initially at 12 m/s. After t = 4 s, the wind velocity drops to 9 m/s and then it is increased to 11 m/s at t = 8 s. The load demand is initially set at 0.6 pu. At time t = 3 s, the load is increased to a value of 0.75 pu and the same load (ie. 0.15 pu) is disconnected from the system at t = 9 s as shown in Fig. 10-(e). The AC voltage at PCC is shown in Fig. 9-(b). It can be seen that the AC load voltage is not affected by the wind speed or resistive load step changes. A sudden voltage excursion can be seen at t = 9.25 s which corresponds to the clutch out of the diesel engine (ie. synchronous generator to condenser mode) as evident from Fig. 10-(b). At t = 9.25 s the SG goes into the motoring mode before changing to the SC mode of operation thus causing voltage excursions in the system as evident from Fig. 10-(b) and Fig. 9-(b). The load side voltage stays within $\pm 1\%$ of its rated value during normal operation. Fig. 9-(c) shows the frequency of the system voltage. As expected, it is closely regulated about the rated value of 1.0 pu and is not seen to be influenced by the wind speed change, load step change and mode transition of the SM (ie. SC to SG and vice versa). The frequency is maintained within ± 1 Hz during normal operation. The frequency is mainly regulated by the DFIG control applied to its RSC. The proposed frequency control methodology of the DFIG is independent from the shaft speed and resistive load condition of the system. Hence, as anticipated, the frequency is not seen to be affected by the above mentioned transient conditions. The DC link voltage of the DFIG is depicted in Fig. 9-(d). The simulated behaviour of the DC link voltage shows that it is well regulated at its rated value throughout the operation except during load and wind step changes, and state transitions of the synchronous machine (ie. synchronous condenser to synchronous generator and vice versa). However, the highest DC link voltage variations are seen to occur at t = 7 s and t = 9.25 s which corresponds to the mode transition of the synchronous machine as evident from Fig. 10-(b). Even during the transient conditions, the DC link voltage variation is limited to within ± 5% of its rated value.

The wind power variation of the system is shown in Fig. 10-(a). For simulation purposes, initially the slip of the wind turbine is set to s = - 0.1 which corresponds to super synchronous mode of operation. According to the wind turbine characteristics, the corresponding maximum power output of the wind generator is 0.73 pu at a shaft speed of 1.2 pu for a wind speed of 11 m/s. From Fig. 10-(a), the power output of the DFIG is seen to rise to a value of 0.73 pu at t = 4 s. At this time the load demand is set to 0.6 pu. The additional power is dissipated in the dump load as shown in Fig. 10-(d). At time t = 3 s, the load of the system is increased to 0.775 pu and the power deficit is then supplied by the fuel cell system as evident from Fig. 10-(c). At t = 4 s, the wind

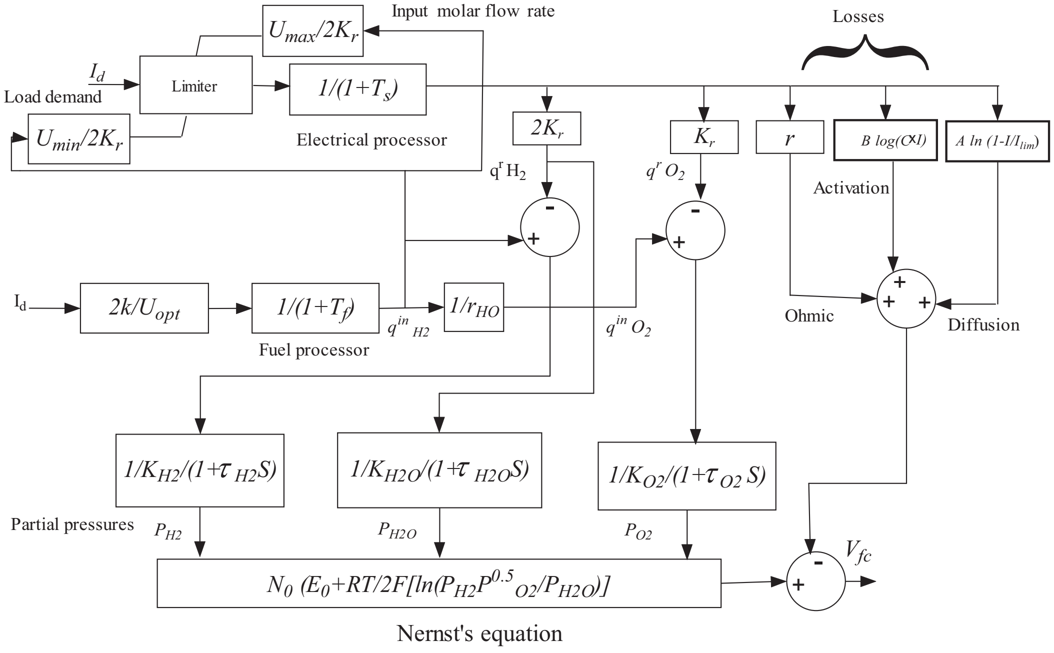

Fig. 6. Detailed model of the SOFC system

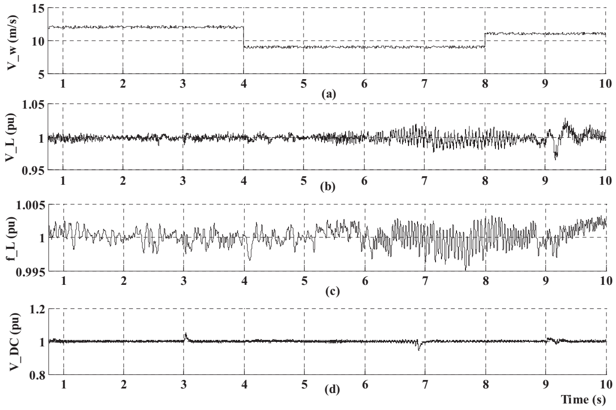

Fig. 9. Response of the RAPS system under variable wind and load conditions. (a) wind speed, (b) voltage at PCC, (c) frequency at PCC, and (d) DC link voltage

speed is reduced to 9 m/s causing reduction in wind power output. When the difference between the load demand and wind power, $P_L - P_w$, is greater than 0.3 pu of synchronous machine rating, the condition under which the diesel generator should operate is fulfilled. However, the synchronous machine still acts as a synchronous condenser and needs extra time to reach its rated speed (ie. 1 pu) to transfer the required torque to perform as a SG. At nearly t = 7 s, the SM changes its mode of operation from SC to SG as evident from Fig. 10-(b). The diesel generator keeps generating power until the load step down which occurs at t = 9 s. After t = 9 s, the synchronous machine changes its mode of operation from SG to SC and the required power is then supplied entirely by the DFIG and fuel cell system.

The performance of the fuel cell throughout the operation is shown in Fig. 11. It can be seen that the fuel cell voltage reduces considerably when it injects power into the system as evident from Fig. 11-(a). The current injected by the fuel cell is shown in Fig. 11-(b). Due to operational limitations, the maximum current provided by the fuel cell is limited to 200 A. The pressure variations of the hydrogen and oxygen are shown in Figs. 11-(c) and (d) respectively.

V. CONCLUSIONS

This paper has investigated the hybrid operation of a novel wind-diesel-fuel cell remote area power system . The system performance has been investigated in relation to the bandwidth of the voltage regulation capability under variable load and wind conditions. The system voltage and frequency are regulated within acceptable limits during both steady-state and dynamic conditions including load and wind speed step changes. The mode transition of the synchronous machine which is implemented using a clutch system provides better active and reactive power support for the system. The control logic associated with the clutch system ensures smooth transition from wind-only to wind-diesel mode of operation and vice versa. The fuel cell operation is activated in the absence of the diesel generator and is able to provide the required deficit power to the system. From the simulated behaviour, it can be seen that the fuel cell performs well throughout the operating period. However, the voltage variation of the fuel cell should be kept within safer limits. Incorporating a super capacitor to the system would be an attractive solution to regulate the fuel cell voltage.

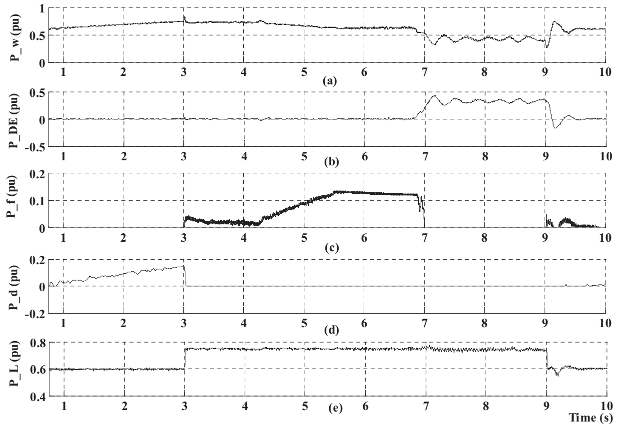

Fig. 10. Power sharing of the RAPS system under variable wind and load conditions. (a) wind power, (b) diesel power, (c) fuel cell power, (d) dump load power and (e) load demand

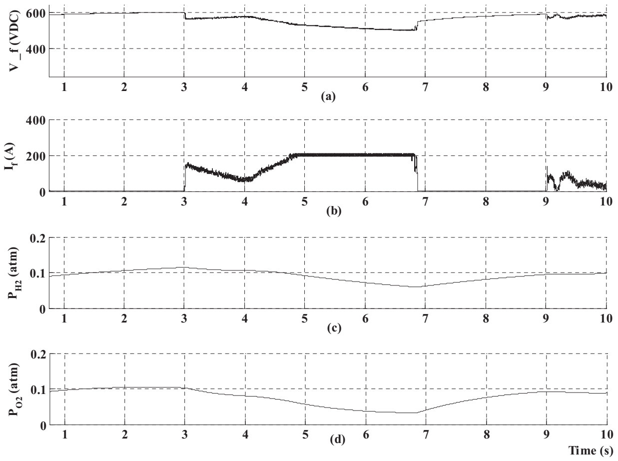

Fig. 11. Behaviour of fuel cell system (a) fuel cell voltage (b) fuel cell current, (c) partial pressure of Hydrogen and (d) partial pressure of Oxygen

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REFERENCES

[1] T. Senjyu, T. Nakaji, K. Uezato and T. Funabashi, “A Hybrid Power System Using Alternative Energy Facilities in Isolated Island”, *IEEE Transaction on Energy Conversion*, vol. 20, issue 2, Jun 2005, pp. 406 - 414.

[2] Z. Chen and Y. Hu, “A Hybrid Generation System Using Variable Speed Wind Turbines and Diesel Units”, *IEEE Ind, Electron. Soc. Annual Meeting Conference, Virginia, USA*, vol. 3, 2 - 6 Nov. 2003, pp. 2729 - 2734.

[3] N. Mendis, K. Muttaqi, S. Sayeef and S. Perera, “ Power Generation in Isolated and Regional Communities: Application of a Doubly-Fed Induction Generator Based Wind Turbine”, *19th Australasian Universities Power Engineering Conference, Adelaide, Australia*, 27 - 30 Sept. 2009, pp. 1 - 7.

[4] E. Muljadi and J. T. Bialasiewicz, “Hybrid Power System with a Controlled Energy Storage”, *IEEE Ind, Electron. Soc. Annual Meeting Conference, Virginia, USA*, vol. 2, 2 - 6 Nov. 2003, pp. 1296 - 1301.

[5] L. H. Tay, W. W. L. Keerthipala and L. J Borle, “ Performance Analysis of a Wind/Diesel/Battery Hybrid Power System”, *Australasian Universities Power Engineering Conference, Perth, Australia*, 23 - 26 Sept. 2001, pp. 107 - 112.

[6] R. Takahashi and J. Tamura, “Frequency Control of Isolated Power System with Wind Farm by Using Flywheel Energy Storage System”, *18th International conference on Electrical Machines, Vilamoura, Portugal*, 6 - 9 Sept. 2008.

[7] T. F Tsao, P. H Chen and H. G Chen, “Dynamic Modeling and Simulation of Hybrid Power Systems Based on Renewable Energy”, *International Conference on Energy and Environment Technology, Guilin, China*, 16 - 18 Oct. 200p, pp. 602 - 605.

[8] B. Palle, M. G Simoes and F. A Farret, “Dynamic Interaction of an Integrated Doubly-Fed Induction Generator and a Fuel Cell Connected to Grid ”, *36th IEEE Power Electronics Specialists Conference, Recife, Brazil* , Jun. 200p, pp. 185 - 190.

[9] E. Muljadi, C. Wang and M. H. Nehrir, “Parallel Operation of Wind Turbine, Fuel Cell, and Diesel Generation Sources”, *Power Engineering Society General Meeting, Denver, United States* , 6 - 10 Jun. 2004, vol. 2, pp. 1927-1932.

[10] M. Gaiceanu and G. Fetecau, “Grid Connected Wind Turbine-Fuel Cell Power System Having Power Quality Issues”, *International Conference - Electrical Power Quality and Utilisation, Barcelona, Spain*, 9 - 11 Oct. 2007, pp. 759 - 64.

[11] R. Pena, R. Cardenas, G. M. Asher J. C. Clare, J. Rodriguez and P. Cortes, “Vector Control of a Diesel-Driven Doubly Fed Induction Machine for a Stand-Alone Variable Speed Energy System”, *Industrial Electronics Society, IEEE 28th Annual Conference, Sevilla, Spain*, vol. 2, 5 - 8 Nov. 2002, pp. 985 - 990.

[12] R. Sebastian, “Smooth Transition from Wind Only to Wind Diesel Mode in an Autonomous Wind Diesel System with a Battery-Based Energy Storage System”, *International Journal of Renewable energy - Scince Direct*, vol. 33, 4 May 2007, pp. 454 - 466.

[13] F. Katiraei and C. Abbey, “Diesel Plant Sizing and Performance Analysis of a Remote Wind-Diesel Microgrid”, *Power Engineering Society General Meeting,Tampa, Florida, USA*, 24 - 28 Jun. 2007, pp. 1 - 8.

[14] S. Sayeef, N. Mendis and K. Muttaqi, “Optimisation of Component Sizes for a Hybrid Remote Area Power Supply System”, *19th Australian Power Engineering Conference, Adelaide, Australia* , 27 30 Sept. 2009, pp. 1 - 6.

[15] Y. Zhu and K. Tomsovic, “Development of Models for Analyzing the Load-Following Performance of Microturbines and Fuel Cells”, *Electric Power Systems Research*, vol. 62, 2002, pp. 1 - 11.

APPENDIX A
PARAMETERS OF RAPS SYSTEM- BASE POWER 1000 KW

Rating of wind turbine generator	750 kW
Rating of diesel generator	350 kW
Fuel cell system	150 kw
DFIG speed range of operation	0.7 pu-1.3 pu
Rated DC link voltage of back-to-back converter	750 V
Rated load side voltage	400 V
Operating frequency	50 Hz