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Design and development of a self-supported polymer electrolyte fuel cell system with anodic dead-end operation

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Abstract: Design and operational details for a self-supported polymer electrolyte fuel cell (PEFC) system with anodic dead-end fuel supply and internally humidified cathodic oxidant flow are described. During the PEFC operation, nitrogen and water back diffuse across the Nafion membrane from the cathode to the anode and accumulate in the anode flow channels affecting stack performance. The accumulated inert species are flushed from the stack by purging the fuel cell stack with a timer-activated purge valve to address the aforesaid problem. To minimize the system complexity, stack is designed in such a way that all the inert species accumulate in only one cell called the purge cell. A pulsed purge sequence comprises opening the valve for purge duration followed by purge-valve closing for the hold period and repeating the sequence in cycles. Since self-humidification is inadequate to keep the membrane wet, the anodic dead-end-operated PEFC stack with composite membrane comprising perflourosulphonic acid (Nafion) and silica is employed for keeping the membrane humidified even while operating the stack with dry hydrogen and internally humidified air.

Keywords: polymer electrolyte fuel cell, dead-end, self-supported, purge sequence, composite membrane, self-humidification

1 INTRODUCTION

A polymer electrolyte fuel cell (PEFC) is considered a promising alternative power source for automotive and stand-alone stationary applications owing to its high efficiency, low temperature, and easy-start operation with zero emission. However, PEFC systems happen to be expensive. Accordingly, it is desired to enhance the performance of PEFCs, and make them simpler and cost-effective. In a PEFC system, oxidant air is supplied by a blower or a compressor depending on the system requirement. Accordingly, it is desirable to optimize the auxiliary power consumption of the system while hydrogen fuel needs to be used efficiently and economically as, unlike atmospheric air, it is not freely available. Power densities in excess of 250 mW/cm^2 are required for realizing small PEFC systems for certain need-based niche applications [**1**].

There are three typical ways of fuelling hydrogen to PEFCs, namely:

(a) dead-end,
(b) flow-through,
(c) re-circulation.

In the dead-end mode, the outlet of the anode is blocked such that hydrogen is supplied at the rate similar to its consumption avoiding the need of a flow controller. However, pure hydrogen needs to be used in this mode to avert any accumulation of inert species. In the flow-through mode, however, hydrogen is discharged to the atmosphere from the anode leading to discharge of unspent hydrogen fuel into the atmosphere. In the re-circulation mode, the excess hydrogen from the anode outlet is re-circulated to the anode inlet [**2**]. The latter needs additional auxiliary power for the re-circulation pump. By contrast, a dead-ended anode can be fed with dry hydrogen at

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constant pressure at exactly the rate needed to support the reaction. Fuel cell operation with dry hydrogen in a dead-ended system is supported by back diffusion of water crossing through the membrane. The use of a pressure regulator in place of a mass-flow controller and removal of anode-inlet humidification will help lowering both system weight and cost. The only problem with this architecture is that nitrogen from air fed to the cathode that can diffuse across the membrane under the pressure gradient, creating a blanket of N_2. Water vapour gradients between the humidified cathode and the dry-fed anode also drive excess water into the anode, which can cause significant liquid water accumulation. Unlike water vapour, whose maximum partial volume is dictated by temperature, liquid can fill the free space and block the flow of reactants.

Ahluwalia and Wang [**3**] have reported that hydrogen-fuelled-PEFC stacks operating at <100 per cent fuel utilization per pass with the anode exhaust gas being recycled to the anode inlet. In this process, the inert gas present in the anode gas increases in concentration as the hydrogen is consumed. Consequently, a portion of the re-circulating anode gas is purged to prevent excessive build-up of the inert gases. It is also observed that nitrogen in the air diffuses across the polymer electrolyte membrane from the cathode to the anode, adding to the volume of the inert gases in the anode channels. Nitrogen crossover from the cathode to the anode gas channels depends on a number of factors, namely the power level, nitrogen content in the hydrogen fuel, purge rate from the re-circulating anode gas, and the membrane-electrolyte thickness. With pure hydrogen, the steady-state nitrogen concentration in the anode could reach as high as 50–70 per cent at low purge due to the nitrogen crossover from the cathode to the anode. This nitrogen build-up could be reduced to 5–20 per cent with a moderate purge of 2 per cent of the anode exhaust gases. With pure hydrogen there is a voltage decrease of 10–18 mV if the nitrogen concentration is allowed to reach between 25 per cent and 60 per cent. This voltage decrease could be reduced to <5 mV by increasing the purge rate to limit the nitrogen concentration between 2 per cent and 25 per cent. Both the build-up of nitrogen and purging a portion of the re-circulating gas degrade the stack efficiency, but the latter limits the nitrogen build-up. In brief, the optimum purge rate minimizes the degradation in the net efficiency of the PEM stack due to nitrogen build-up and varies with the nitrogen content in the hydrogen fuel, fuel cell membrane thickness, and hydrogen utilization per pass.

Yoshioka *et al.* [**4**] have reported a 0.4 kW 20-cell PEFC stack using gaseous reactants gases at 74 per cent relative humidity (RH) at the cathode and 75 per cent RH at the anode with an average voltage degradation of ∼1.5 mV/1000 h while operating for 5000 h at $75 \pm 0.5\,^{\circ}C$ with water coolant. The stack used anode gas comprising 25 per cent CO_2, 75 per cent H_2, and 10 ppm CO, while ambient air was supplied to the cathode. The utilization of fuel and oxygen was set at 75 per cent and 40 per cent, respectively. Giddey *et al.* [**5**] have reported the construction and evaluation of a water-cooled 1 kWe PEFC stack that was constructed and evaluated in stages of 2-, 4-, 8-, and 15-cell with an active area of 225 cm^2 per cell. Hydrogen and air were humidified and supplied to stacks operating in the flow-through mode at temperatures between 22 and 25 °C. The stack cooling water was also supplied in once through the mode at 22 and 25 °C. The stack temperature was kept at 65 °C. An electrical efficiency of 41 per cent and combined heat and power (CHP) efficiency of 80 per cent with external thermal insulation were achieved with the stacks. A small degradation in performance of the stacks was observed due to increase in the average ohmic resistance of cells from 0.328 to 0.428 ohm cm^2 after subjecting to more than 40 cold start/shutdown thermal cycles and ∼300 h of accumulated operation over a period exceeding 1 year. Possible causes for increase in ohmic resistance between various stack components are attributed to corrosion of the current collection plate, and deterioration of the catalyst, carbon paper, and diffusion layer. Jer-Huan *et al.* [**6**] have reported that increase of anode humidification increases the overall stack performance. The difference between performances of each cell in the stack increases with cell temperature and stack performance increases with cathode gas stoichiometric ratio. The performance of the stack increases as torque applied is increased from 60 to 80 in lbf. A five-cell air-cooled PEM fuel cell stack was designed and realized and systematic studies on the influence on the humidification of the reactant gases were carried out to optimize the operative conditions by Urbani *et al.* [**7**]. Polarization curves and lifetime test at a fixed load current have been conducted for various relative humidity cathode (RHC) and relative humidity anode (RHA) inlet humidity conditions. In particular, a small decay and low performance are obtained for RHA and RHC <70 per cent, while a considerable decay and low performance is found for RHA and RHC >70 per cent. A good compromise for water management, in terms of decay and performance, is obtained when a symmetrical RH of 70 per cent is used, because in this case an optimal water balance is reached due to high flow of gases. In fact, insufficient water content implies lower proton conductivity for the membrane while excess water results in flooding of the electrodes and parasitic losses due to the presence of water in the gas channels. Consequently, these effects lead to a lowering of stack voltages during lifetime tests. The cathode RH has stronger influence on the stack decay in relation to the anode. At optimal RH, a constant and stable power of about 55 W at 20 A is obtained during the 15 h of operation. St-Pierre *et al.* [**8**] have reported the performance of the Standard Ballard Mk513 eight-cell stack to

demonstrate that the water management in PEFCs is an important parameter to optimize its peak performance. These authors have shown the detrimental effects of impurities on cell performance, improper water balance (i.e. either too wet or too dry conditions, and the effect on cell degradation rates). They have also identified several areas for further development related to these issues that include the identification of the membrane and electrode assembly (MEA) contamination modes and related control strategies, the need for more data on the effects of different water levels within a PEFC on performance degradation and materials characteristics over long periods of operation, and elucidation of fundamental mechanism leading to a mass transport loss due to improper water management within the PEFC.

Susai *et al.* [**9**] have reported on the development of a 1 kW PEFC operating on an exclusive method of internal humidification. The important feature of this humidification method is direct supply of liquid water to the hydrogen channels with gaseous hydrogen. Hydrogen and water are supplied to the hydrogen channel through a fine opening in the header located at the upper side of the gas separator. A constant supply of water to the hydrogen channel allows the hydrogen gas to move over water vapour to keep the anode wet. As a result, the solid-polymer-electrolyte membrane could be kept appropriately wet throughout regardless of the operating status. These authors have developed carbon/resin plates with the gas flow channels and peripheral area made from a heat-resistant resin, while current flows through the carbon part. According to Knobbe *et al.* [**10**], a practical solution to the problem of unequal cell-to-cell gas and water distribution is to employ sequential purging for individual or groups of cells to ensure proper water management. The concept of variably controlling the exhausts of each cell has been applied with air operation in small (16 cm^2 active area) and large (94.3 cm^2 active area) stacks comprising five and six cells. A 30 per cent increase in the power output of a PEM fuel cell stack could be achieved by applying this concept [**10**]. Karimi *et al.* [**11**] have shown that the performance of PEFC stacks could be improved significantly by optimizing the design and operating conditions using the flow-network approach.

In the literature, a model for the operation of a PEFC with internal humidification of the feed gases has been reported and its operating conditions using dry H_2/air were studied. The model predicts that dry air fed at the cathode can be fully internally humidified by the water produced by the electrochemical reaction at temperatures up to 70 °C. This model was experimentally validated for cell temperatures up to 60 °C by long-term operation of a PEFC with dry gases for up to 1800 h. The load current densities obtained at 0.6 V were 20 per cent and 40 per cent lower at reactant pressures of 3 and 1 atm, respectively, than those measured when both the gases were humidified. The water distribution in the PEFC operating with dry gases was investigated by measuring the amount of product water on the anode and cathode sides. It was found that the back diffusion of product water from the cathode to the anode was critical for water management in the cell over a wide range of operating conditions. The dominant water back diffusion also allowed internal humidification of hydrogen fuel and prevented anode drying [**12**].

In the literature, power-generation characteristics at 80 °C for the dead-end-operated-hydrogen-fed PEFC with dry-air-fed cathode while keeping the gas pressures on both the anode and the cathode at 0.15 MPa were reported by Hikita *et al.* [**13**]. Influence of humidity on cell voltage had been studied by varying the amount of hydrogen and introducing the steam at the anode.

A free-breathing PEFC in a dead-end mode has also been reported in the literature at two different hydrogen pressures and humidification levels while varying the duty cycle of the purge valve. It was observed that the cell could operate with both dry and humid hydrogen while keeping the anode outlet closed. A slight decrease in cell performance was observed with the closed purge valve compared to the periodically opening valve. The cell was able to operate in the dead-end mode at high fuel utilization rates and high overall system efficiency. However, the cell needed a purge valve in order to avert water flooding during its long-term operation; the purge valve was also required to flush the anode during the start-up [**14**].

The operation and accumulation of liquid water within the cell structure of a PEFC with the dead-end anode has been studied in the literature using neutron imaging. The measurements were performed on a single cell with 53 cm^2 active area, Nafion 111 membrane, and carbon cloth gas-diffusion layer. In spite of subjecting the supply of dry hydrogen to the anode under regulated pressure, accumulation of liquid water in the anode-gas-distribution channels was observed in most test conditions. Furthermore, the accumulation of liquid water in the anode channels was followed by a significant voltage drop. Anode purges and cathode surges were also used as diagnostic tools for differentiating between anode and cathode water flooding. The rate of accumulation of liquid water, and its impact on the rate of cell-voltage drop was shown for a range of temperatures, current density, cathode inlet RH, and air-stoichiometry [**15**]. Siegel *et al.* [**16**] have provided a model and have experimentally validated the evolution of liquid water and nitrogen fronts along the length of the anode channel in a PEM fuel cell operating with dead-ended anode fed with dry hydrogen. The accumulation of inert nitrogen and liquid water at the anode causes a voltage drop, which is recovered by purging the anode. Experiments were designed to show the effect of N_2 blanketing, water plugging of the

channels, and flooding of the gas-diffusion layer. The observation of each phenomenon was facilitated by concomitant gas chromatography measurements on samples extracted from the anode channel to measure the nitrogen content and neutron tomography to measure the liquid water distribution. A model for the nitrogen accumulation is presented, which describes the dynamic evolution of a N_2 blanketing front in the anode channels leading to the development of a hydrogen-starved region. The prediction of the voltage drop between purge cycles during clear channel conditions is shown. Performance of 1 kW PEFC stacks as a part of BPS Nexa™ power module is evaluated by Yoshio *et al.* [**17**]. The stack had a specified net output power of 1.2 kW at full load. Hydrogen and air were supplied to the inlet of two gas channels formed in the flow field plates and fuel outlet of the stack was dead-ended. The system comprised a 47-cell PEFC stack connected in series, an air cooling fan, and a blower for reactant air supply to the stack and to the oxidant humidifier. The stack efficiency is reported as 45.6 per cent at 960 W power output. Fuel to electrical and thermal energy conversion is reported to be 37.8 per cent and 54.7 per cent, respectively. Wenhua *et al.* [**18**] have performed the uniformity analysis under a load of 800 W for all MEAs in 10 individual Nexa 47-cell stacks. MEAs in different stacks had the same lower voltage at the 46th and 47th cells in relation to other cells. The lower voltages of these cells reduced the high power capability for the stack, primarily caused by gas distribution problem, water flooding/low reaction-temperature at the compressor side. Wenhua *et al.* [**19**] added a manual purge line into the exterior fuel exhaust stream of a Ballard PEM stack in a Nexa power module. By the addition of manual exhaust purge, high levels of inert gases were intentionally added to the anode feed without changing normal operational procedures. A new method for determining the critical minimum flowrate in the anode exhaust stream was given by an anode mass balance. By this type of operation, membranes in MEAs were used both as gas purifiers and electrolytes. The PEM stack was operated with up to ca. 7 per cent nitrogen or carbon dioxide in the absence of palladium-based hydrogen separator at ca. 200 W power level. Nitrogen in the anode stream was concentrated from 7.5 per cent to 91.6 per cent. The system maintained a fuel efficiency of 99 per cent at a manual purge rate of 2.22 ml/s. The fuel cell stack efficiency was 64 per cent, the stack output efficiency was 75 per cent, and the overall system efficiency was 39 per cent. Young-Jun *et al.* [**20**] studied the operating conditions affecting the performance of air-cooled PEFCs designed for portable applications. The experiments were conducted with 16- or 21-cell stacks with an active area of 100 cm^2 per cell at varying humidity values of 37, 48, and 66 per cent, respectively. The MEA comprised a Nafion 112 membrane and SGL carbon as the gas-diffusion layer. The manifold design was important to make the distribution of volume flowrate uniform. The U-shaped configuration was found to be more uniform than the *z*-shaped configuration. The deviation of distribution in the U-shaped configuration was under 1 per cent. In doing so, need to estimate the parasitic load of the air compressor, actuators, and control board was realized.

Eckl *et al.* [**21**] have reported the performance of a commercial 300 W_e self-humidifying PEFC stack from heliocentris energy systems. The computer-controlled fuel cell system is designed for operation with hydrogen and air. The stack comprised 20 water-cooled single cells, each with an active area of 49 cm^2. GORE PRIMEA 5510 MEAs were used with a membrane thickness of 25 μm and a Pt loading of 0.3 mg/cm^2 on the anode and the cathode, respectively. Gas-diffusion layers were GORE CARBEL CL gas-diffusion media. The reactant gases and the cooling liquid were fed in parallel to the individual cells of the stack. Hydrogen and air were passed in cross-flow mode by a two-channel meander on the anode side and a four-channel meander on the cathode side of each single cell. Hydrogen was fed into the stack in the dead-end mode from a gas bottle via a pressure reducer, a main valve, and a flow meter. In order to remove inert gaseous-residue and product water originating from back diffusion, a solenoid purge valve was attached to the anode exhaust. Depending on the load current, the purge valve was periodically activated for about 1 s by the control program. For stack cooling, distilled water was pumped in a closed loop with a cooler and a variable speed fan. Self-humidifying operation of the stack as well as optimization of electrical power output was possible, and excessive dryness or humidity was prevented by carefully adjusting the operating conditions.

In the literature, a mathematical model has also been developed to predict the nitrogen content of an anode with high fuel utilization. The nitrogen-permeability coefficient through the membrane had been estimated by comparing the experimental results with the mathematical model analysis. Simulation indicated considerable nitrogen build-up at the outlet. To estimate the nitrogen crossover, the gas concentration at the outlet of the anode stream was measured, and compared to the model. A UTC Fuel Cells inter-water-management cell design with 400 cm^2 active area was used for the experiments. A gas-sampling port was installed at the fuel outlet. A portion of the total gas stream was continuously analysed with gas chromatography and the nitrogen concentration at the outlet was measured at varying load current densities [**22**].

A PEFC stack operating in anodic dead-end mode is also reported in the literature. The flush frequency of the anode was investigated. In order to optimize hydrogen usage, the flush frequency was calculated from system modelling according to the operating conditions. A model that simulates the water exchange

between the anode and the cathode channels in the anode dead-end mode was reported [**23**].

It is clear from the aforesaid literature survey that water management is seminal for PEFC stacks, especially operating under reduced humidity conditions. In this study, composite membranes have been used for operating PEFC stacks under reduced humidity conditions enabling simpler PEFC system configuration with improved power density. This study also reports a PEFC system operating on dry hydrogen with dead-end anode operation and internally humidified air. In order to improve the output power density while operating the PEFC stack with dry hydrogen, the Nafion–silica composite membrane is used in place of the Nafion membrane. The performance characteristics of both the PEFC stack and the PEFC system are reported.

2 DESIGN AND DEVELOPMENT OF THE PEFC STACK

Fuel cell performance directly depends on the conductivity of the polymeric membrane which in turn depends on the water content of the membrane. The membrane can be kept wet by means of a humidification process. In a PEFC stack, humidification of the oxidant can be achieved by external humidification or internal passive humidification. External humidification offers excellent control over the extent of humidification of the reactant but at the expense of high parasitic loss. Internal or passive humidification uses product water from fuel cell and needs little auxiliary power but has the disadvantage of limited control over humidification [**24**].

Inadequate hydration of the perfluorosulfonic acid membrane leads to mechanical stress in the membrane and promotes its failure such as tearing and cracking durability. It has also been shown that low RH operation accelerates chemical degradation of proton exchange membranes. To this end, Nafion–silica composite membranes suitably modified with ceramic/inorganic fillers, namely SiO_2, TiO_2, ZrO_2, etc., are widely used to facilitate proton conductivity in the membranes at elevated temperatures even under low RH conditions [**25**]. The Nafion–silica composite membrane was obtained by a novel water hydrolysis sol–gel process wherein a homogeneous, transparent, and less viscous silica sol is first prepared without any acidic or basic environment followed by incorporation of the required amount of sol into the Nafion matrix. The sol enters the fine pores of perfluorosulphonic acid (PFSA) and due to the acidic nature of the latter forms Si–OH network in the pores, which on heating at 90 °C under vacuum culminate as Si–O–Si linkages, forming a composite membrane. The composite membrane exhibits appreciable proton conductivity at elevated temperatures even at low RH values.

Although flow-through operation is used at both the anode and the cathode of most laboratory/experimental PEFC systems, the fuel utilization at the anode flow-through operation happens to be too low in commercial and portable systems. For achieving optimum performance with a PEFC system, stack should be designed to achieve as high fuel utilization as possible. One of the simplest operating choices is the dead-end-mode operation wherein the reactant fuel is generally substantially pure. However, purging is inevitable even with substantially pure hydrogen in dead-end-mode system to obtain stabilized power output. In this configuration, hydrogen is supplied at the rate needed to support the reaction. Fuel cell operation with dry hydrogen in dead-ended-system architecture is possible because water crossing through the membrane is found adequate to keep the membrane wet. The use of a pressure regulator in place of a mass-flow controller and elimination of anode humidification make the system simple and help reducing both its cost and weight. The problem with this architecture is that nitrogen and water from air diffuse across the membrane creating a blanket of nitrogen and water. In open-mode operation, the fuel to the individual cells is distributed in parallel architecture. If the parallel-mode supply is adapted in the dead-end mode, the inert molecules accumulate in all the cells. Accordingly, to initiate the purge process, all the cells have to be monitored that makes the control system highly complex. To simplify the control system, the fuel supply as shown in Fig. 1 is adopted. In this parallel-series combination, all but one cell are connected in parallel. Thus, the inert gas that crosses over from the cathode to the anode in the stack is allowed to accumulate only in the last cell. Thus, purge process can be initiated by monitoring only the purge cell that makes the control system simple. As shown in Fig. 1, inert components in the fuel stream accumulate in the purge cell during operation because of the cascaded flow design [**26**]. The build-up of the inert species in the purge cell affects the performance of the purge cell. To mitigate it, a fuel purge valve is provided at the fuel-stream outlet of the stack which is activated by a controller to regulate flow from a fuel cell stack when the voltage across a purge-cell portion of the fuel cell

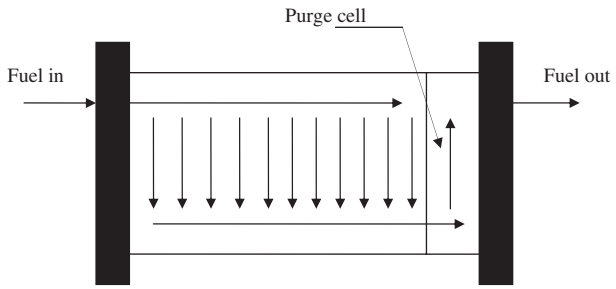

Fig. 1 Schematic description of cascaded-flow design

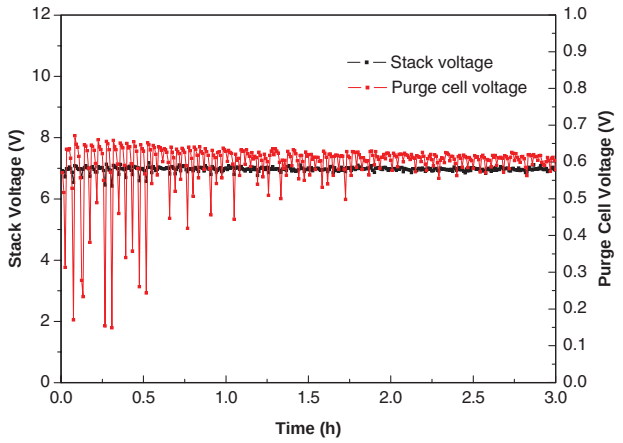

Fig. 2 Optimization of purge sequence

stack falls below the threshold voltage. The controller operates for pre-defined purge durations to simplify the architecture and operation of the fuel cell system. In this study, the controller activates the purge valve in a pulsed purge sequence whenever fuel-cell-stack purge is desired. A pulsed purge sequence comprises opening the valve for purge duration, closing the purge valve for a hold period, and repeating this sequence in cycles [**27**]. Purge sequence is optimized to balance the minimum fuel wastage and purge cell voltage stability as shown in Fig. 2.

3 PEFC SYSTEM DESCRIPTIONS

A PEFC stack is undoubtedly the heart of the fuel cell system but auxiliary units are mandatory to support it. The fuel cell system typically comprises:

(a) oxidant supply,
(b) fuel supply,
(c) thermal management,
(d) water management,
(e) power conditioning,
(f) instrumentation and controls.

A self-supported PEFC system comprises a PEFC stack, a membrane humidifier, a centrifugal blower, solenoid valves, a pressure regulator, an air pump, two 12 V–7 Ah batteries, DC–AC inverter, and programmable logic control panel. The notable feature of the system is that it does not depend on power supply from the grid for start-up operation. The system has provision to charge the batteries. Initially, the batteries meet the power required to start the air pump and delivery of hydrogen to the stack through the solenoid valve. Once the fuel cell is fed with the reactants and is ready for operation, the auxiliary power (air pump = 70 W, air blower = 14 W, and two solenoid valves = 6.8 W), for the fuel cell system is sustained by the fuel cell.

A 300 W self-supported PEFC system operating with the dead-end-mode fuel supply, passive membrane humidification, and air as coolant is designed and developed as shown in the flow diagram depicted in Fig. 3.

The stack used in the self-supported system comprises 12 cells with an active area of 120 cm^2 per cell. MEAs are obtained following the procedure reported elsewhere [**25**]. Dry hydrogen gas is fed to the fuel cell, which operates in dead-end-fed mode at <5 psig by using a pressure regulator. A needle valve and a solenoid valve are connected at the outlet of the anode end-plate to regulate the purge-flowrate. Fresh air from an air pump is pumped through a membrane humidifier (Model No. FC125-240-5PP, Perma Pure LLC) against the wet outlet-air from the PEFC stack. The humidified air from the membrane humidifier is fed to the PEFC stack cathode inlet. The air pump can control the air flowrate by adjusting the DC voltage signal (0–5 V) to the pump. The air blower is connected to the system to remove the heat and the speed of the air blower is controlled by a temperature-control-module driven by the stack temperature so as to minimize the auxiliary power consumption. The stack temperature is maintained at ~55 °C.

After optimization of all the parameters the integration of PEFC stack with balance-of-plant is carried out to realize the PEFC system as shown in Fig. 4. The overall performance of PEFC system-I is depicted in Fig. 5. To meet the reduced RH condition, a PEFC stack using the recast Nafion–silica composite membrane is

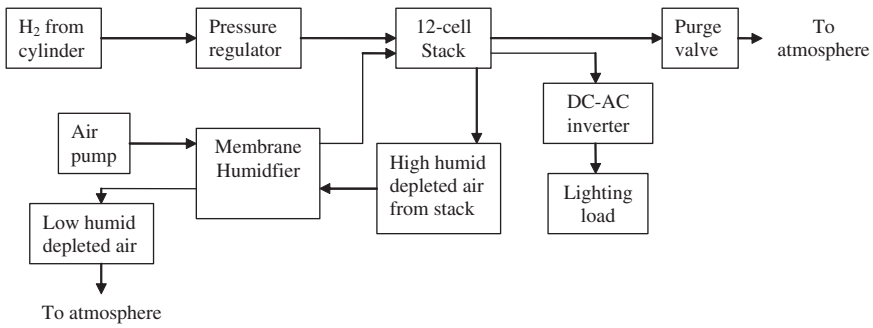

Fig. 3 Flow diagram for the self-supported PEFC system

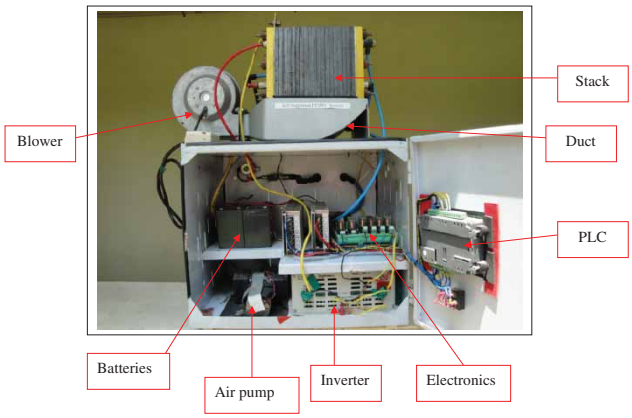

Fig. 4 Self-supported 300 W PEFC system

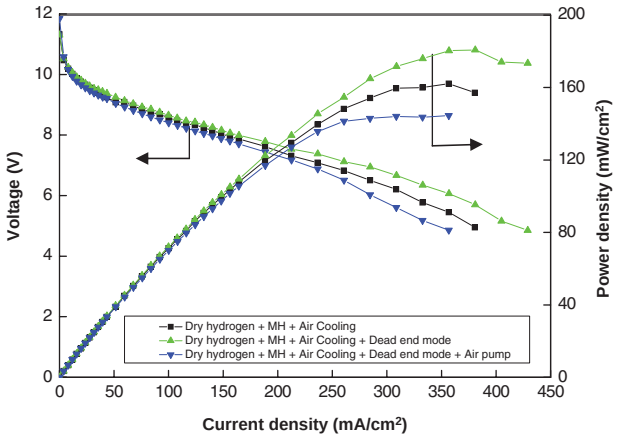

Fig. 5 Performance curve for PEFC system-I

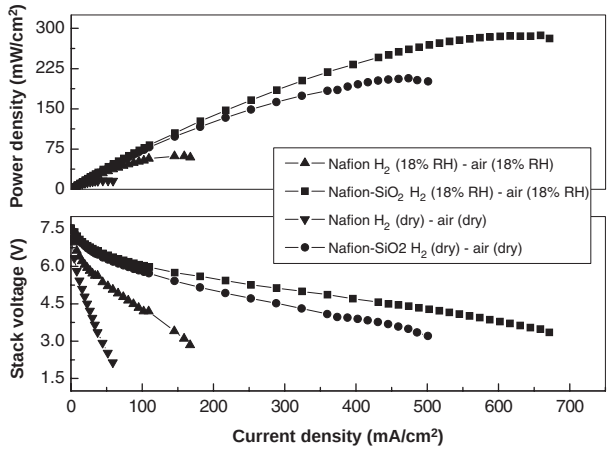

Fig. 6 Performance curve for PEFC system-II

assembled (PEFC system-II) and performance tested as shown in Fig. 6. The role of the self-humidifying membrane (Nafion–silica) studied here is important when the PEFC is operating at low RH values. The hydrophilic filler particles, such as SiO_2 present in the Nafion matrix, absorb water and act as a water reservoir to keep the membrane wet even at low RH values. This helps the PEFCs to sustain periods of inlet-stream draught without excessive loss in membrane conductivity. The maximum load current densities reached in MEAs comprising Nafion and Nafion–silica composite membranes are 450 and 700 mA/cm^2, respectively. In the current-density regions studied here, the characteristic trend for mass-transfer polarization is not observed. PEFC systems comprising stacks containing Nafion and Nafion–silica composite-based MEAs have been operated at 200 and 300 mA/cm^2, respectively, at an average cell voltage of 0.6 V for nearly 500 h.

4 CONCLUSIONS

A PEFC stack with maximum fuel utilization operating in the dead-end mode without external humidification is developed. This stack is integrated with necessary auxiliary components to realize a self-supported 300 W PEFC system. It is shown that incorporation of self-humidifying composite membranes in PEFC stacks ameliorates the performance.

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