Crimson Publishers
Wings to the Research

Mini Review

Dynamic Energy Management for Real Time Control of Battery Less PV-Wind Powered Desalination Unit

Wahib K*, Mehdi T and Jamel B

Laboratoire des Systèmes Electriques Ecole Nationale d'Ingénieurs de Tunis, Université de Tunis El Manar, North Africa

ISSN: 2640-9739

***[1]Corresponding author:** Wahib K, Université de Tunis El Manar, LR 11 ES 15, Laboratoire des Systèmes Electriques Ecole Nationale d'Ingénieurs de Tunis, BP 37-1002, Tunis le Belvédère, Tunisie, North Africa

Submission: February 25, 2020

Published: August 02, 2021

Volume 2 - Issue 2

How to cite this article: Wahib K, Mehdi T, Jamel B. Dynamic Energy Management for Real Time Control of Battery Less PV-Wind Powered Desalination Unit. COJ Elec Communicat. 2(2).COJEC.000532.2021.
DOI: 10.31031/ COJEC.2021.02.000532

Abstract

In this paper we present a Dynamic Energy Management System elaborated to share available electrical energy, provided by a battery less hybrid source (PV-Wind), between motor-pumps used in desalination process. This Dynamic Energy Management System is combined to Power Field Oriented Control to maintain DC bus voltage stability and to control electrical power of motor-pumps used for water pumping and/or reverse osmosis desalination. Simulation and practical results are demonstrated and discussed to evaluate the power sharing performances and "Water-Energy" cooperative control effectiveness.

Keywords: Dynamic energy management system; Hybrid renewable source (PV-wind); Power field-oriented control; Three- phase centrifugal motor-pump; RO desalination

Introduction

Drinking water is increasingly scarce and polluted. It has become a strategic issue. To compensate this water lack, Reverse Osmosis (RO) desalination represents an effective solution which is experiencing strong progression with the improvement of techniques used [1-3]. Coupling the complementary renewable source "PV-Wind" to RO desalination process offers a sustainable source of freshwater [4-8]. To ensure autonomous operation of the system and to reduce installation cost while ensuring drinking water availability, we have chosen to eliminate the electrochemical storage in battery and to replace it with hydraulic storage. Electrical power and hydro-mechanical flow control is based on Power Field Oriented Control (PFOC). This control is applied to motor-pumps through voltage inverters in order to ensure pumping and/or desalination operation and to control the DC bus voltage stability without using battery storage [9]. A Dynamic Energy Management System (DEMS) is combined to PFOC to determine the appropriate electrical power value for each motor-pump.

The global system architecture Figure 1 is composed of:

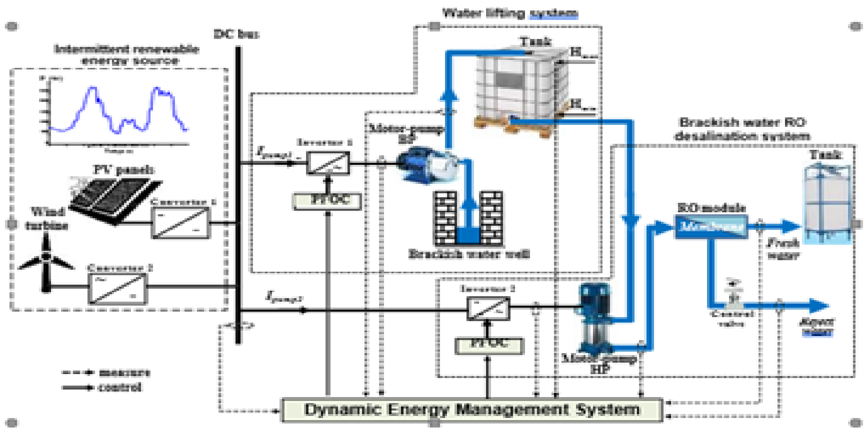

Figure 1: Global system architecture.

a) Hybrid renewable energy source (PV-Wind) coupled to DC bus through static converters.

b) Water lifting system consisting of a low pressure centrifugal three-phase motor-pump (Motor-pump-BP) and a raised water tank for hydraulic storage.

c) Brackish water RO desalination system consisting of a high pressure centrifugal multi-stage three-phase motor-pump (Motor-pump-HP) and a spiral RO filtration membrane placed in module.

An experimental desalination test bench with capacity of 300l/h was designed to study the different control strategies and to analyze electrical power transfer from the equivalent power source to RO potable water production unit [10].

Dynamic Energy Management System and Power Field Oriented Control

Hybrid electrical source (PV-Wind) chosen to supply the water production unit has a topology connected to a DC bus. The Dynamic Energy Management of the global system requires that DC bus voltage Vdc is maintained constant despite electrical power fluctuation supplied by the source. In order to channel energy flow from hybrid source to hydro-mechanical loads, a power control system is mandatory. This control should take advantage of the different freedom degrees offered by each converter in order to manage rationally energy and water flows. A preliminary analysis of freedom degrees for motor-pump connected to hydraulic network and fed with finite capacity electrical power source, shows that the operating point of the system "converter/motor-pump/hydraulic load" is locked to an operating point fixed by the electrical power provided. In contrast, for a conventional system where the motor-pump is fed with electrical network, we seek to optimize energy efficiency or water flow rate. The goal of the DEMS is to calculate in real time the power sharing factor α to be applied to PFOC to impose a reference electrical power for each motor-pump according to (2) and (3).

$$\mathcal{P}_{pump\text{-}BP} = \alpha \cdot \mathcal{P}_{src} \quad (1)$$

$$\mathcal{P}_{pump\text{-}HP} = (1\text{-}\alpha) \cdot \mathcal{P}_{src} \quad (2)$$

In the absence of any electrical storage unit and taking into account the preceding analysis, the control of DC bus voltage can be insured by Motor-pump-HP or Motor-pump-BP indifferently. However, the decision is up to the DEMS to choose which motor-pump to operate and what value of electrical power to give for each one (Figure 2). The advantage of using PFOC is to have a decoupled control of the induction motor magnetic state Φr and the DC bus voltage V_{dc} [11,12] (Figure 3). This is done by virtue of power conservation relationship at Voltage Source Inverter (VSI) which can be written by neglecting losses:

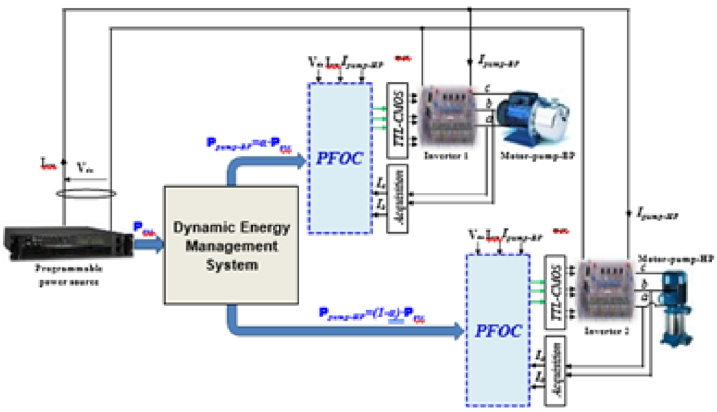

Figure 2: Synoptic diagram of DEMS and PFOC.

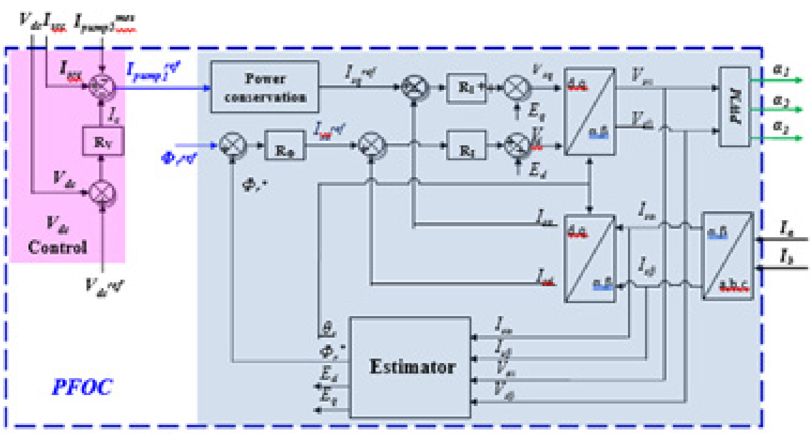

Figure 3: Power Field Oriented Control synoptic diagram.

$$V_{dc}.I_{pump} = V_{sd}.I_{sd} + V_{sq}.I_{sq} \quad (3)$$

Fundamental requirements for the PFOC as inputs are a knowledge of two-phase currents (the third phase current is also known since $I_a+I_b+I_c=0$) DC bus voltage V_{dc}, Hybrid source current I_{src} and the second motor-pump current I_{pump2}. To validate all control strategies on the brackish water desalination test bench (Figures 4 & 5), PFOC was discretized for practical implementation on *DSpace DS1104* control board using a sampling period of 5 10^{-5}s, measured phase currents I_a and I_b were sampled and converted by a 16-bit A/D converter. For the control of I_{sd} and I_{sq} current related to flux component reference and DC bus voltage component reference respectively, classic numerical PI (Proportional and Integral) regulator is well suited to regulate Φr and Vdc feedback to the desired values as it is able to reach constant references, by correctly setting both the P term (K_p) and the I term (K_i) which are respectively responsible for the error sensibility and for the steady state error. The numerical expression of the PI regulator is given by (4) and represented by Figure 6.

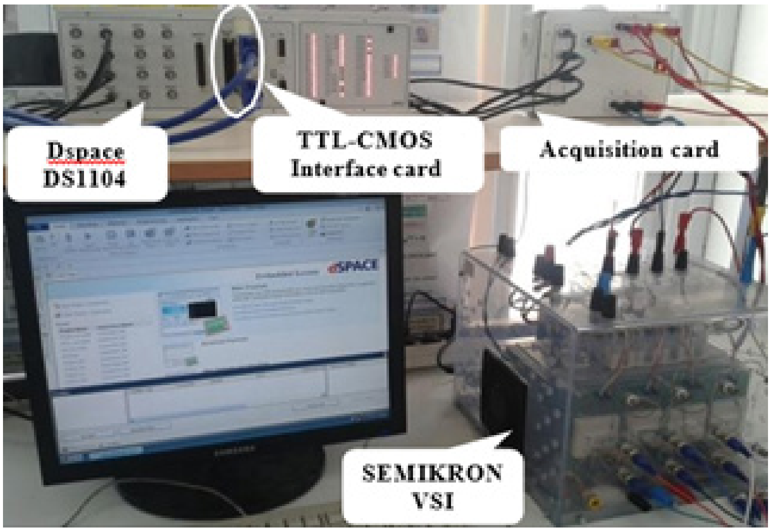

Figure 4: Experimental environment.

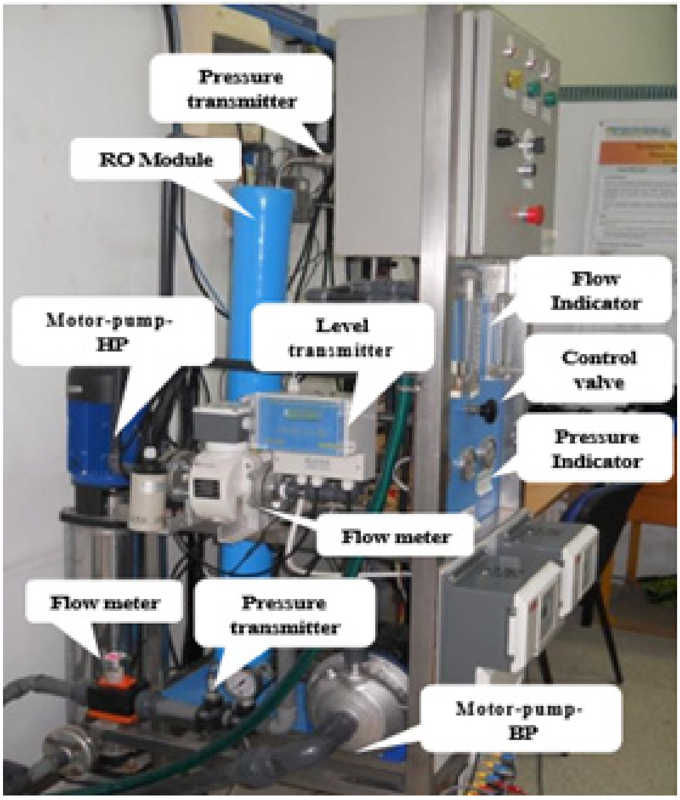

Figure 5: Experimental test bench.

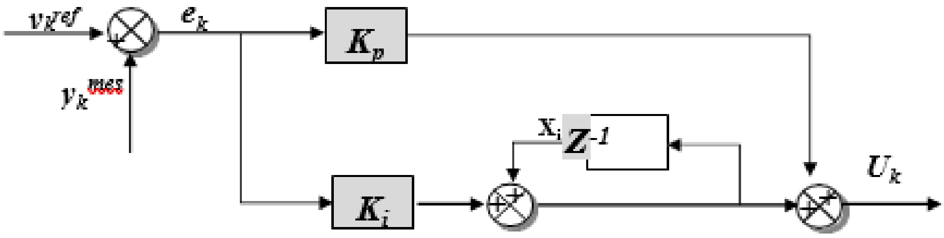

Figure 6: Numerical PI regulator Structure.

$$U_k = K_p e_k + K_i e_k + \Sigma e_n \quad (4)$$

In validation phase, the renewable source was emulated using a programmable power supply that can generate a variable power profile up to 4kW [13] (Figure 7). Experimental tests were carried out through a basic Energy Management System (EMS) that determines the reference power to be applied with PFOC control [14]. In these tests, Motor-pump-HP was chosen to control DC bus voltage and Motor-pump-BP to control electrical power through a Variable Frequency Drive (VFD) Santerno Sinus N using the implemented PID controller (Figure 8).

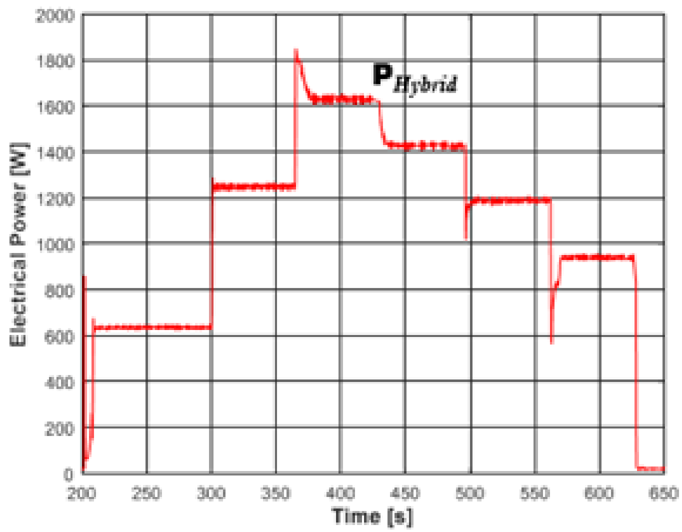

Figure 7: Hybrid PV-Wind power source evolution.

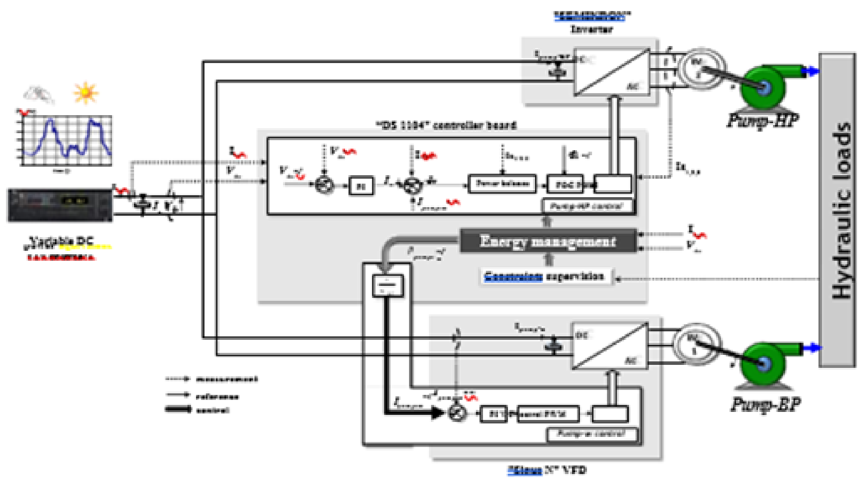

Figure 8: Experimental tests structure.

Figure 9 shows performances of DC bus voltage control loop through the control of motor-pump-HP I_{sq} current. Figure 10 shows performances of rotor flux control through the control of motor-pump-HP I_{sd} current. Experimental results show good performances in terms of response time and robustness to the severe test fluctuations provided by the equivalent power source. The DC bus voltage is maintained stable at 320V despite variations in the electrical power source. Evolution of feed water flow and pressure are shown in Figure 11. Feed water flow rate varies from 15l/min for 630W electrical power supply to 23 l/min for 1630W. Feed water pressure varies from 6.6bar to 13.2bar for the same power range. Once we have validated PFOC strategy with a basic EMS, we focused on the elaboration of a dynamic EMS used to share available electrical power between hydro-mechanical loads by alternating DC bus control between the two motor-pumps.

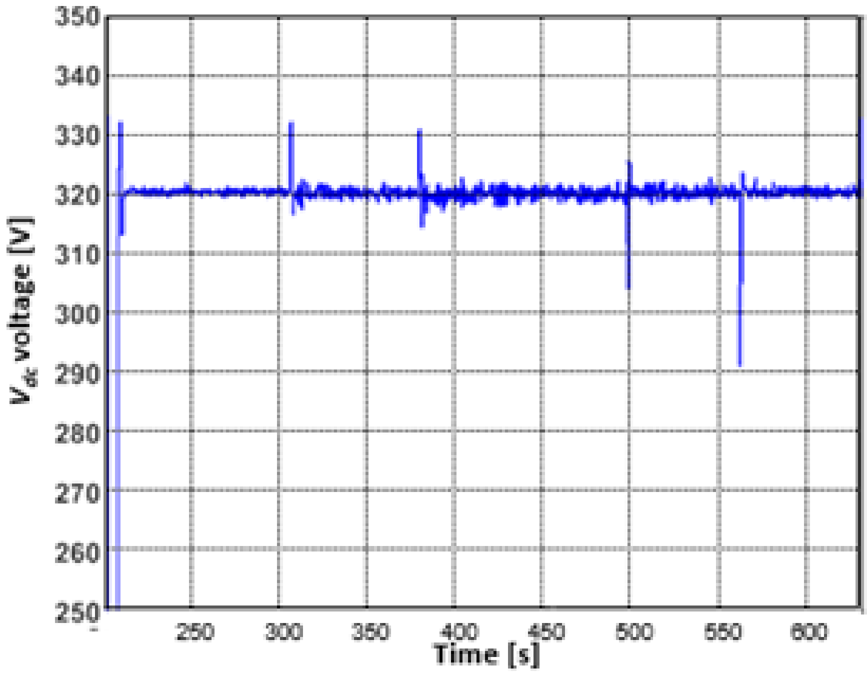

Figure 9: DC bus voltage control.

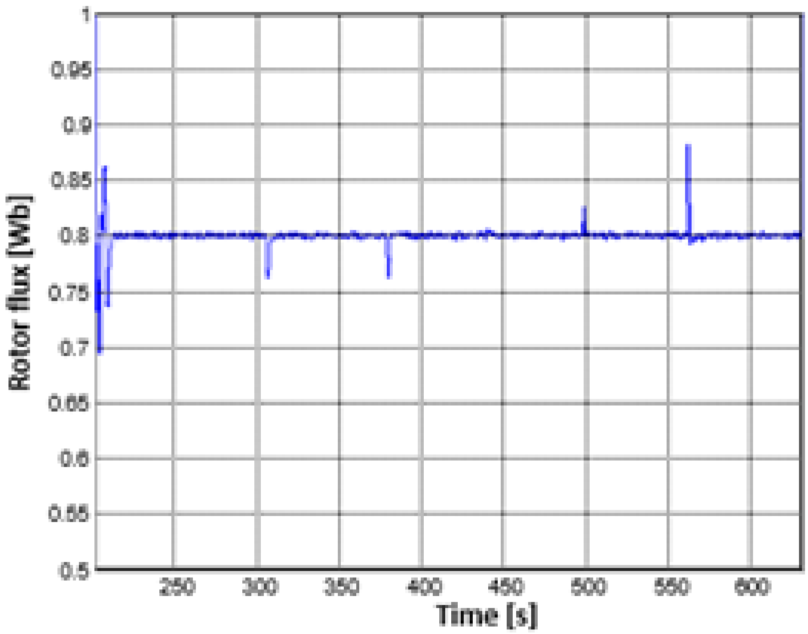

Figure 10: Rotor flux control.

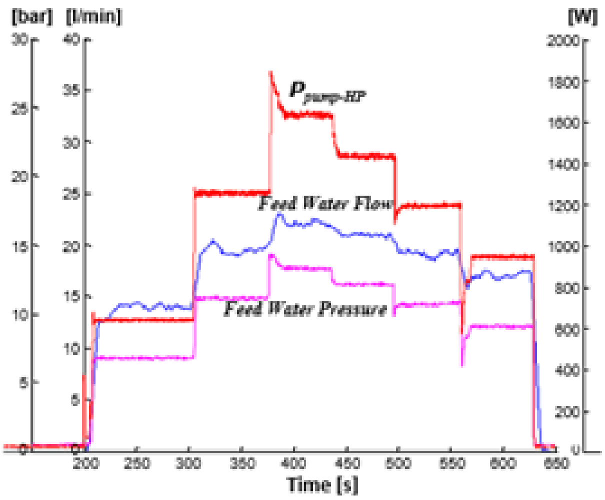

Figure 11: Feed water flow and pressure variation.

Dynamic Energy Management Simulation Result

Mathematical models of hybrid (PV/Wind) power source, Motor-pump-HP, Motor-pump-BP and RO membrane was developed and simulated using Matlab software. The different parameters of the simulated system are chosen as below:

a) The wind speed was chosen between 4 to 20m/s, ambient temperature equal to 25°C and solar irradiance is 1000W/m^2.

b) The DC-Bus voltage reference value is set to 230V.

c) The motor-pump rotor flux Φr reference value is set to 0.8Wb.

d) The feed water salinity of brackish water equal to 4500ppm (4.5g/l).

e) The BWRO unit operates with a fixed recovery ratio (Y=20% when the motor-pump operate at nominal power).

f) PFOC and DEMS has been discretized and simulated with the whole system using a sampling period of 5 10^{-5}s.

The test bench experimental characterization allowed to define the motor-pumps operating range (Tables 1-3). Evolution of the hybrid electrical power is shown in Figure 12. Peak electrical power reaches 2527W at 9s and 315W at 23.6s. PV electrical power has a constant value of 1000W for the first 15s then decreases for 10s until reaching 0W at 25s. Electrical power sharing between Motor-pump-BP and Motor-pump-HP is shown in Figure 13. In this scenario, Motor- pump-HP operates alone from 0s to 4s. Then, from 4s to 11.6s both motor-pumps are in operation. From 11.6s to 23s Motor- pump-HP continues to operate alone before stopping for a second from 23s to 24s and then resume operation. We notice that in all cases the DEMS ensures that the maximum power of each motor pump $\mathcal{P}$max is not exceeded. The excess of electrical power provided is dissipated using auxiliary loads or stored in small battery used to feed sensors and electronic devices. Figure 14 shows performances of DC bus voltage control insured by V_{dc} control loop of PFOC strategy. Reference value is set to 230V. Simulation results show the swiftness and effectiveness of the control to stabilize DC bus voltage for a wide range of electrical power variation (from 315W to 2527W) and without using batteries in the system. The control of DC bus voltage is done by Motor-pump-HP from 0s to 23s and by Motor-pump-BP from 23s to 24s. Evolution of water flow rate and pressure for Motor-pump- BP and Motor-pump-HP are shown in Figures 14 & 15 respectively. It is noticed that these two hydraulic quantities follow the evolution of electrical power with a slower dynamic for feed water flow.

Table 1: Motor-pumps electrical power range.

Motor-pump	Pump-BP	Pump-HP
Minimal electrical power $\mathcal{P}_{min}$ [W]	130	350
Maximal electrical power $\mathcal{P}_{max}$ [W]	520	1,920

Table 2: Motor-pump-Bp characteristics.

Model	LOWARA CEA 70/3
Rated power	370W
Rated voltage	230V
Rated current	2.51A
Rated frequency	50Hz
Rated speed	2820rpm/min
Rated flow	30-80l/min
Rated pressure	1.3-2 bar

Table 3: Motor-pump-Hp characteristics

Model	EBARA EVM2 22F/2.2
Rated power	2200W
Rated voltage	230V
Rated current	8.71A
Rated frequency	50Hz
Rated speed	2860tr/min
Rated flow	20-60l/min
Rated pressure	8.2-18.6 bar

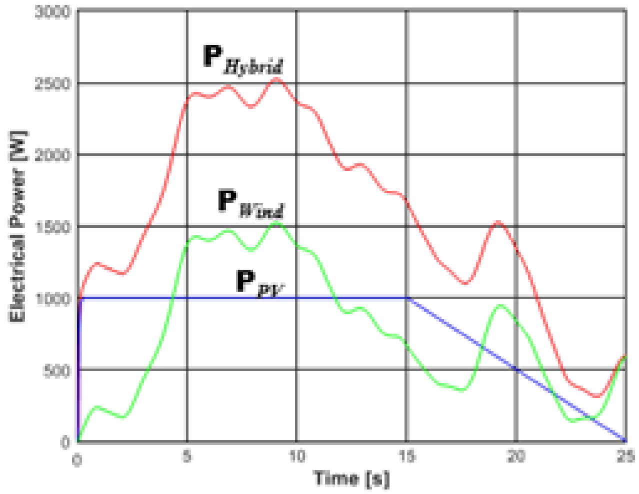

Figure 12: Electrical power evolution.

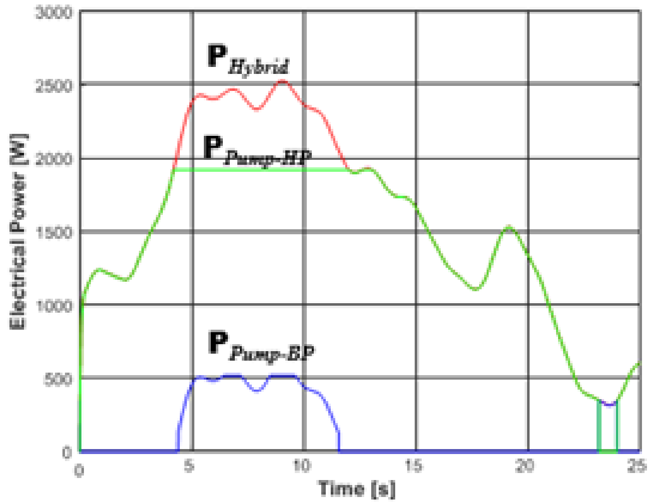

Figure 13: Electrical power sharing.

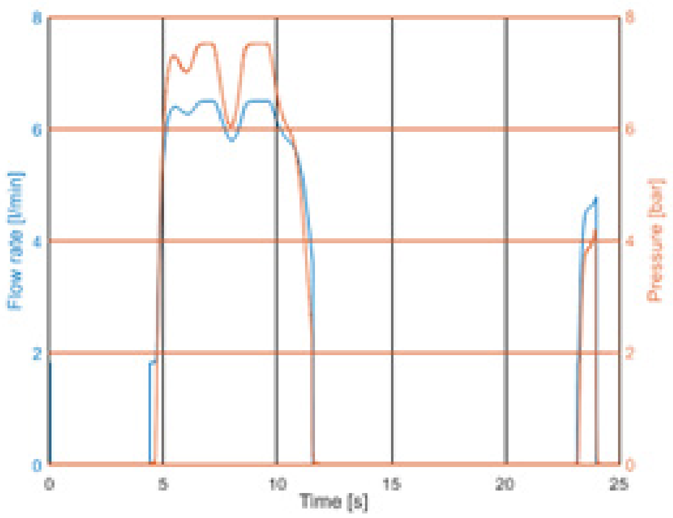

Figure 14: Motor pump BP water flow rate and pressure variation.

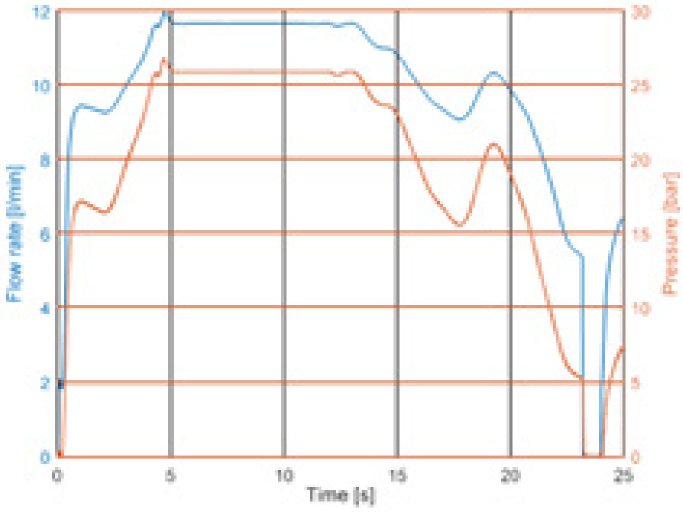

Figure 15: Motor-pump-HP water flow rate and pressure variation.

Conclusion

In this work we presented a Dynamic Energy Management System combined with Power Field Oriented Control used to operate a battery less renewable energy powered RO desalination prototype. PFOC was validated experimentally for Motor-pump-HP. DEMS was simulated with PFOC to validate power sharing between motor-pumps and DC bus voltage control insured by both motor-pumps. Simulation results allowed to study the dynamic behavior of the desalination unit in case of fast electrical power fluctuations supplied by a renewable source.

Acknowledgment

This work was supported by the Tunisian Ministry of Higher Education and Research under Grant LSE–ENIT-LR 11 ES15 and the European project “ERANETMED - EDGWISE” ID 044.

References

1. Dubreuil A, Assoumou E, Bouckaert S, Selosse S, Maizi N (2013) Water modeling in an energy optimization framework-The water-scarce middle east context. Appl Energy 101: pp. 268-279.
2. Greenlee LF, Lawler DF, Freeman BD, Marrot B, Moulin P (2009) Reverse osmosis desalination: water sources, technology, and today’s challenges. Water Res 43(9): 2317-2348.
3. Burn S, Hoang M, Zarzo D, Olewniak F, Campos E, et al. (2015) Desalination techniques - A review of the opportunities for desalination in agriculture. Desalination 364: pp. 2-16.
4. Sharon H, KS Reddy (2015) A review of solar energy driven desalination technologies. Renew Sustainable Energy Reviews 41: pp. 1080-1118.
5. Ghaffour N, Bundschuh J, Mahmoudi H, Goosen MFA (2015) Renewable energy-driven desalination technologies: A comprehensive review on challenges and potential applications of integrated systems. Desalination 356: pp. 94-114.
6. Garg MC, Joshi H (2014) A review on PV-RO process: solution to drinking water scarcity due to high salinity in non-electrified rural areas. Separ Sci Technol 50(8): 1270-1283.
7. Gude VG (2015) Energy storage for desalination processes powered by renewable energy and waste heat sources. Appl Energy 137: pp. 877-898.
8. Buonomenna MG, Bae J (2015) Membrane processes and renewable energies. Renew Sustainable Energy Reviews 43: pp. 1343-1398.
9. Turki M, Rhouma AB, Belhadj J (2009) Experimental characterization of a reverse osmosis desalination process fed by hybrid power source, SSD, Djerba, Tunisie.
10. Khiari W, Turki M, Belhadj J (2016) Prototype expérimental d’un système de dessalement par osmose inverse alimenté par une source renouvelable intermittente sans stockage électrochimique “Conception et caractérisation pour la gestion Energie-Eau”. CISTEM Marrakech, Maroc.
11. Rhouma AB, Belhadj J, Robaom X (2008) Control and energy management of a pumping system fed by hybrid Photovoltaic-Wind sources with hydraulic storage: Static and dynamic analysis - U/f and F.O.C controls methods comparisons. JES 4(4): 1-29.
12. Rhouma AB, Belhadj J, Robaom X (2013) Theoretical and experimental investigation for storage less control of a water pumping system fed by intermittent renewable sources, SESDE, Athènes, Grèce.
13. Khiari W, Rhouma AB, Turki M, Belhadj J (2014) DSPACE implementation and experimentation of Power Field Oriented Control for motor-pump fed by intermittent renewable sources. CISTEM 2014, Tunis, Tunisie.
14. Turki M, Belhadj J, Roboam X (2014) Water/Energy management approaches of an autonomous water desalination unit fed by a hybrid (Photovoltaic-Wind) system. CISTEM, Tunis, Tunisie.

