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Interactive website with systems analysis environment for prefeasibility studies of small scale water and power production units integrating renewable energy

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Abstract: This paper focuses on *RESYSproDESAL* systems analysis environment (SAE) for the prediction of technical, economic and ecological performance of water and power point systems including desalination (e.g. membrane and thermal processes), renewable energy sources for power (e.g. wind energy and photovoltaics) and conventional power supply (e.g. Diesel GenSet).This tool was developed within EU FP6 projects in cooperation between EU-MENA countries. The SAE is applied to a small scale container system for 10 m³/day seawater reverse osmosis desalination powered from Diesel and photovoltaics. Starting from a reference design case three alternative configurations and size are developed and analysed for comparison. The results show a considerable potential for economic improvement of the plant concept, bringing the project closer to affordability for the target population: Optimized Diesel and battery sizes reduce levelised water cost by about 15 %. Up-sizing the whole system from 10 to 50 m³/d and power recovery reduce specific power consumption by about 45 % and integration of water production with village power supply may meet user needs better and increase reliability of back-up.

Keywords: Desalination, Renewable Energy, Co-Generation, Performance, Systems Analysis

1. Introduction

Most Middle East and Northern Africa (MENA) countries are facing growing problems of water supply. Impressive efforts are dedicated to the implementation of large scale equipment with well proven cost-effective technologies for central sea water desalination at coastal sites or brackish water desalination near inland cities. However there are many technically neglected places remote from the countries' centres of water and power production. Typically such settlements of few hundred people with no clean underground water depend from long distance transport of water by truck with high risks due to limited reliability of driver, vehicle and fuel supply as well as hygienic deficiencies of equipment. The true cost of such methods of supply is often not evaluated by the responsible authorities. If grid power connection is not at reach the village may have a simultaneous problem of water and power supply. The inhabitants of such places deserve safer and cost-effective solutions for satisfaction of their needs for an acceptable standard of living. Water and power production should be implemented on site employing appropriate technologies and making best use of local resources of energy, material and labour. Therefore European experts in small and medium scale desalination and hybrid power generation from conventional and renewable energy sources are developing engineering methods for Integrated Water and Power Point (IWPP) systems, characterised by flexible design, fast implementation, energy efficiency and low emissions. A consortium composed by ZSW (Germany), NERC (Jordan), MESOteam/UMBB (Algeria) and SimTech (Austria)has been involved in the development of the systems analysis environment (SAE) *RESYSproDESAL* for the prediction of technical, economic and ecological performance of water and power point systems including desalination and water treatment (e.g. membrane and thermal processes), renewable energy sources for power (e.g. wind energy conversion and photovoltaic power generation) and conventional power generator (e.g. Diesel GenSet) Mohammedi, 2006.

The process simulation within this tool is done with the commercial software *IPSEpro* from company SimTech in Austria. The standard library of this programmewas extended with special models for desalination equipment and components for conversion of renewable energy.

The challenge of such systems analysis and engineering stems from the necessarily integrative character for the solutions: Usually only simultaneous water and power production and hybrid utilisation of conventional and renewable energy sources make reliable and cost-effective solutions feasible. The integrative character of the engineering approach is recognised from. Fig. 2, showing a typical case of integrated water and power production by a sea water reverse osmosis (SWRO) desalination plant powered from hybrid fossil/renewable energy conversion from Diesel engine and photovoltaics (PV).

There are two subsystems in this example:

- The water treatment system including sea water intake (or well), pre-treatment tank and dosing of chemicals, high pressure pump, pressure vessels for reverse osmosis, post-treatment and storage of permeate, disposal of concentrate.
- The power supply system including PV generator, Diesel GenSet, electric energy storage (accumulator), inverters DC/AC and reverse, power busbar with load management control system. The busbar may be equipped with connections for another power source, e.g. Wind energy Converter (WEC), and for export of power into a local (village) power grid.

2. Modelling, Simulation and Analysis Environment

The simulation and optimisation of the the 48 m³/day brackish water Reverse Osmosis small scale desalination unit powered from PV and Diesel generatoris done with *RESYSproDESAL* tool under *IPSEpro* System Analysis EnvironmentRheinländer,2003. *RESYSproDESAL* tool for simulation can help design and optimize water-renewable production systems. The standard library of this software was extended using MDK toolkit with Resysprospecfic models for desalination equipment and components for conversion of renewable energy.The challenge of such systems analysis and engineering stems from the necessarily integrative character for the solutions: Simultaneous water and power production and hybrid utilisation of conventional and renewable energy sources make reliable and cost-effective solutions feasible.

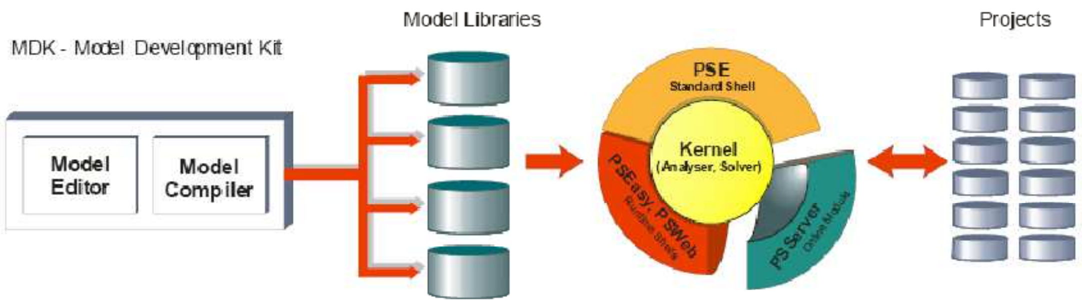

Figure 1: *IPSEpro architecture*

3. Case Studies in Algeria

3.1. Case 1: Azeffoun

Located on the mediteranean coast, 150 km east of Algiers and 20 km east of Azzefoun small village, Asseklu site is in the heart of the ZET (Zone d'ExpansionTouristique) nearby the Guraya National Park. With an annual average of wind velocity at 10 m height of 8.4 m/s, the site should be suitable for wind energy conversion.

The main indicative data of Azzefoun (Asseklu) site case study are summarized below:

Coordinates: 36.9 N,4.7 E, time zone 1
Climate:Mediterranean
Conventional Energy:none
Elevation: 30 m
Pumping head including height of the tank: 10m
Raw water: sea water
WaterSalinty: 40000 ppm TDS
Irradiation:4500 Wh/day min., 5400 Wh/day max.

Population are semi scattered. Houses may have around 60 m distance from each others. Estimated number of population is around 200. Daily demand for potable water is around 40 m^3/day.

3.2. SWRO Desalination

The operation of the system shall aim at a daily production of 10 m³ of potable water. A performance simulation of the integrated RO+PV+Dieselwas done with the RESYSproDESALtool for systems analysis. The process simulation in this tool is done with the commercial software IPSEpro extended with special models for desalination equipment and components for conversion of renewable energyKershman, 2002. The process scheme for the integrated RO+PV+Diesel system is shown in Fig. 1. The scheme is designed for more general applications including another renewable power source (e.g. wind energy conversion) and power supply to a village grid. By setting zero power flows for these connections they are excluded from process simulation.

The simulation of the RO process was done assuming the same set of pressure vessels and membranes as reported: 2 streams with 2 vessels each and 2 membranes type SW30-2540 from FILMTEC per vessel. However the (water) recovery rate calculated here is 49 % against 40 % reported, though in both cases a fouling factor of 0.85 was assumed.

Design Results

Energy

Description	value	Unit
total power requested by SWRO at nominal operation conditions	6.8	kW
specific energy consumption for SWRO process (all auxil. included)	3.07	kWh/m³
power generated by PV system (output from inverter for default op.)	12.3	kW
ratio of annual RE supply to demand from process	0.4606	----
annual consumption of fuel for Diesel GenSet	104198	kg/a
annual energy supplied or consumed		
to desalination process and auxiliary loads	59706	kWh/a
from RE sources via busbar to grid	2757	kWh/a
from RE sources to busbar	27499	kWh/a
from village to grid connection node	0	kWh/a
from grid connection node to village	249040	kWh/a
from Diesel to grid connection node	281247	

Cost

Description	value	Unit
Present Worth		
investment (total plant)	186252	€
investment for desalination system	43593	€
fixed O&M costs (total plant)	257998	€
fixed O&M costs for desalination system	184571	€
variale O&M costs (total plant)	42294	€
variable O&M costs for desalination system	38632	€
replacement costs (total plant)	23854	€
replacement costs for desalination system	10692	€
cost of fuel consumed on site	597571	€
water sold	437451	€
electricity sold	667271	€
net (NPW)	-3247	€
levelised electricity cost (LEC)	0.2345	€/kWh
levelised water cost (LWC)	2.182	€/m³
period for payback of investment from discounted net cash flow	20.4	a

Ecology

Description	value	Unit
annual emission of CO2 from Diesel GenSet operation	343615	kg/a
specific CO2 emission from local electricity production	1.113	kg/kWh

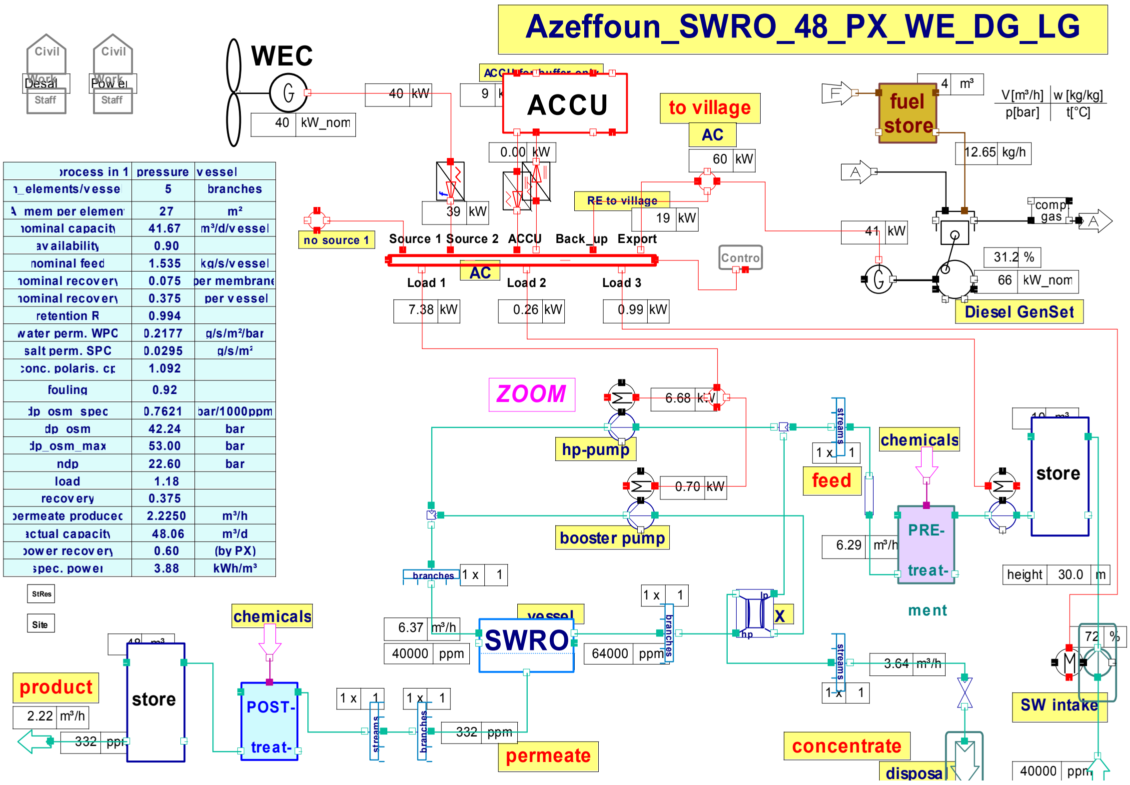

Figure 2 : Desalination process flowsheet

3.3. Case2: Hassikhebbi

Coordinates: 29.2 N,5.4 W, time zone 1
Elevation: 90 m
Pumping head including height of the tank: 10m
Water Salinity: 2000 ppm

Populations are semi scattered. Houses may have around 40 m distance from each others, but this is not a problem since there is an already water network existing from the well to the houses. Estimated number of population is around 600. Daily demand for potable water is around 40 m^3/day

***Figure 4.** Hassi Khebbi Location and view*

3.4. BWRO Desalination

The design of the 48 m³/d brackish water RO powered from PV and Diesel generator with connection to local grid assumes demand for simultaneous supply of water and power to a village Boudieb, 2012. The system is composed from 3 subsystems:

- BWRO brackish water desalination
- PV modules power generation
- Diesel generator set

Energy integration of the subsystems is controlled by a power busbar with load management.

The desalination subsystem includes:

- BWRO water treatment with parallel RO vessels (branches) in parallel streams
- High pressure feed pump in every stream
- Chemical pre- and post-treatment
- Raw water and product storage tanks
- Brackish water intake
- Concentrate disposal
- AC electric motors for all pumps
- Headers for splitting and mixing of streams and branches

Design Results

Cost

Description	value	Unit
Present Worth		
investment (total plant)	69255	€
investment for desalination system	33558	€
fixed O&M costs (total plant)	243284	€
fixed O&M costs for desalination system	181867	€
variale O&M costs (total plant)	33407	€
variable O&M costs for desalination system	29974	€
replacement costs (total plant)	10113	€
replacement costs for desalination system	8511	€
cost of fuel consumed on site	529681	€
water sold	310630	€
electricity sold	575864	€
net (NPW)	755	€
levelised electricity cost (LEC)	0.2014	€/kWh
levelised water cost (LWC)	1.543	€/m³
period for payback of investment from discounted net cash flow		

Energy

Description	value	Unit
total power requested by SWRO at nominal operation conditions	2.8	kW
specific energy consumption for SWRO process (all auxil. included)	1.26	kWh/m³
power generated by PV system (output from inverter for default op.)	3.1	kW
ratio of annual RE supply to demand from process	0.3206	----
annual consumption of fuel for Diesel GenSet	92360	kg/a
annual energy supplied or consumed		
to desalination process and auxiliary loads	24513	kWh/a
from RE sources via busbar to grid	0	kWh/a
from RE sources to busbar	7860	kWh/a
from village to grid connection node	0	kWh/a
from grid connection node to village	249040	kWh/a

Ecology

Description	value	Unit
annual emission of CO2 from Diesel GenSet operation	304577	kg/a
specific CO2 emission from local electricity production	1.113	kg/kWh

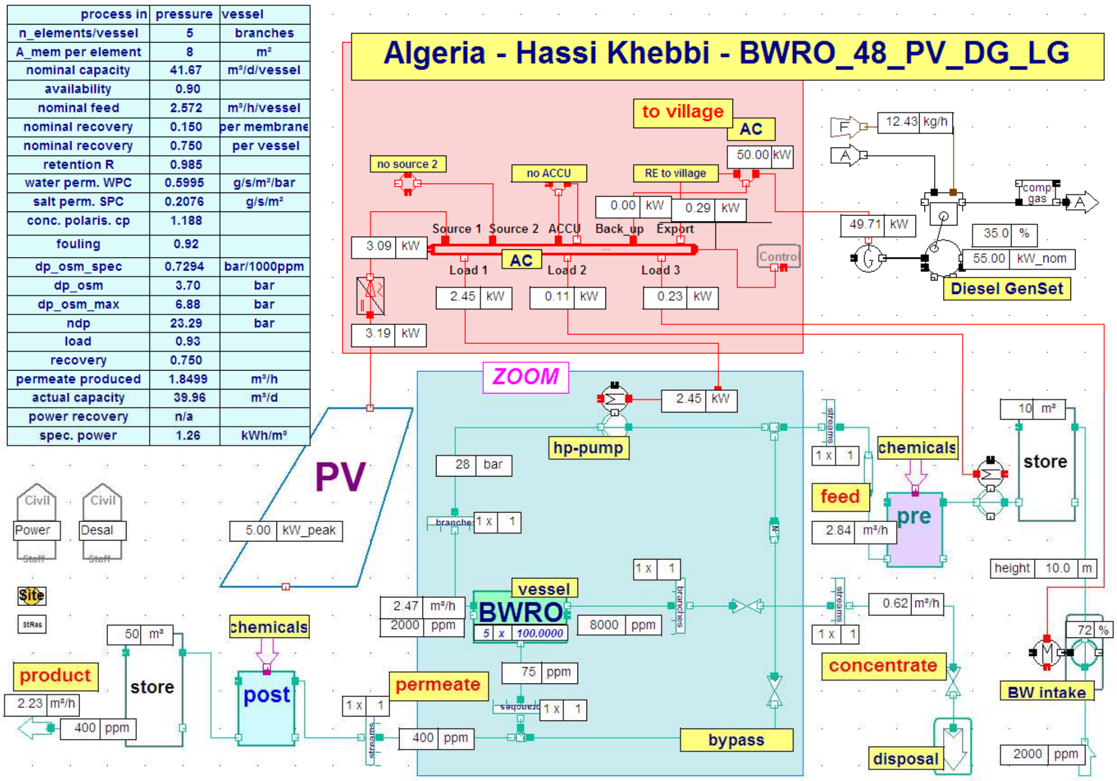

***Figure 5.** Hassi Khebbi case study Ipsepro FlowSheet*

4. Conclusion

In this paper, we presented two case studies with SWRO and BWRO desalination respectively. The results of simulations under *IPSEpro* environment with a case study concerned with a 48 m³/day seawater reverse osmosis (SWRO) desalination in Algeria on the east Mediterranean coastwith up to 60 kW additional power supply to the consumers of the water.The desalination subsystem is large enough to include energy recovery by pressure exchanger. The technical performance simulation predicts more than 80% fraction of the wind power contribution to the annual demand. The results show a potential for economic improvement of the system design reducing the expected levelised water (production) cost from the economic analysis under 2 Euros/m³. Naturally, this case study can be extended to other south Mediterranean countries sharing the same conditions.

The Hassi-Khebbi Brackish water Reverse osmosis desalination plant aims a daily production of 48 m³ of potable water. the integrated RO+WE+Diesel simulation was done with the *RESYSproDESAL* systems analysis tool. The process simulation in this tool is done under IPSEpro extended with special models for desalination equipments and components for conversion of renewable energy. The scheme is designed for more general applications including another renewable power source (e.g. wind energy conversion) and power supply to a village grid. By setting zero power flows for these connections they are excluded from process simulation. With a solar fraction of less than 1/3 of the annual electricity supplied to the BWRO process the originally projected hybrid system more likely is a BWRO Diesel-System with PV for back-up than the opposite.

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