Comparison of MACHINE LEARNING TECHNIQUES used TO MANAGE the variable operation of an SWRO DESALINATION PLANT

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introduction

In *SEAWATER REVERSE OSMOSIS* (SWRO) desalination plants driven by *RENEWABLE ENERGY SOURCES*, ***THE POWER CONSUMED*** depends on:

- the **feed pressure** and
- the **feed flow** rate

which will vary according to the characteristics of the feed water.

It can therefore be of interest TO **IMPLEMENT INTELLIGENT SYSTEMS which generate** the appropriate operating pressure and feed flow **setpoints** which **enable** an operational **energy balance** of the SWRO desalination plant.

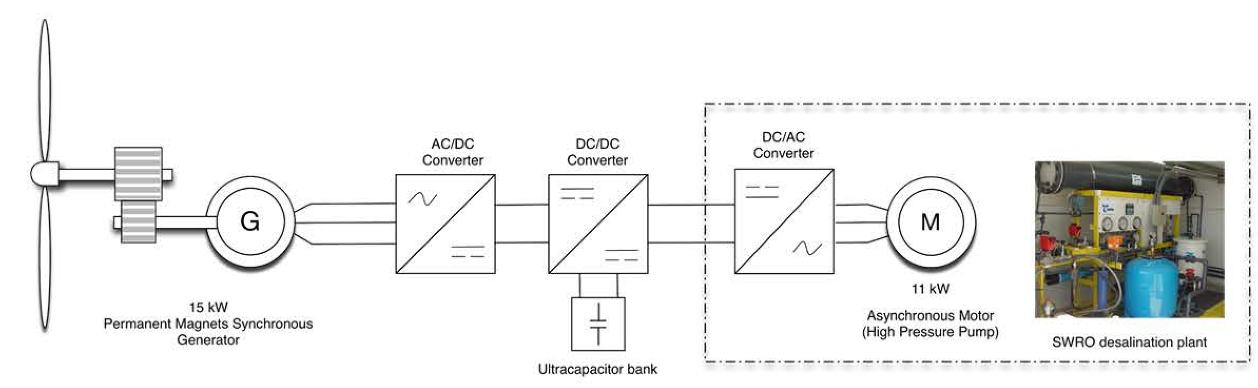

Fig. 1. General configuration of the wind energy based microgrid designed to desalinate seawater.

materials

The SWRO desalination plant will, in the near future, form part of the microgrid whose general configuration can be seen in Fig.1. Under exceptional circumstances, the SWRO desalination plant was disconnected from the microgrid and connected through a frequency converter to the conventional grid.

The devices operated by the control system are shown in Fig. 2, as well as the sensors installed in the plant (the signals of which are recorded by the control system). Also shown is the additional equipment (within the dash-dot line of the detailed view of Mixing-water tank) which was temporarily included in the system for the purpose of selectively modifying the characteristics of the feedwater (conductivity and temperature).

The SWRO is comprised of two pressure vessels, PV1 and PV2, each fitted with three membranes (Toray membranes. Model TM810) in series, which the control system can independently connect/disconnect to/from the system by operating the SV-3 valve. The power demand of the system can be modified when the control system adjusts the operating pressure (by operating the PSV valve) and feed flow of the membranes (by operating the frequency converter which drives the high pressure pump).

methods

The mission of the **Machine Learning (ML) Techniques** in the control system is to **generate the setpoints of pressure, p_{fr}, and flow, Q_{fr},** which are required to enable adaptation of the power consumed to the simulated generated power of a wind turbine. They are taking as **input values:**

- the **power consumption, P_{wt},** of the SWRO desalination plant,
- the **feedwater conductivity, C_f** (conductivity sensor CT2 in Fig.2),
- and **temperature, T_f** (temperature sensor TT2 in Fig. 2),

The steps taken to carry out the tests on the prototype SWRO desalination plant are the following:

one Data collection for the SWRO desalination plant*.

1. The SWRO desalination plant was operated using **one pressure vessel**:
   - the feed flow rate was varied between 1 m^3/h and 3 m^3/h,
   - the conductivity between 48000µS/cm and 56000µS/cm,
   - and membrane input temperature between 20°C and 25°C.
2. The SWRO desalination plant was operated using **two pressure vessels**:
   - the feed flow rate was varied between 3 m^3/h and 6 m^3/h,
   - the conductivity between 48000µS/cm and 56000µS/cm,
   - and membrane input temperature between 20°C and 25°C.

*(This was done by following a sequence of nested loops such that for each set of three values of these variables the operating pressure was regulated until a steady state permeate recovery rate was obtained within the narrow range of between 13.5% and 13.6%).

two Selection, configuration and evaluation of three Machine Learning Techniques**:

- Artificial Neural Networks (ANN)
- Support Vector Regression (SVR)
- Random Forests (RF)

**4 models for each ML technique were build: one for each configuration (one or two pressure vessels) and output (pressure setpoint or flow setpoint).

three Testing for statistical significance between errors of the three techniques.

1. two-by-two ANOVA comparisons between errors of three models
2. adjusted p-values calculation using the procedure proposed by Benjamini and Hochberg for multiple comparisons.

conclusions

The analysis undertaken has demonstrated the ability of these three Machine Learning techniques to generate accuracy operating setpoints of an SWRO desalination plant. With them it is possible to adapt the energy consumption of the plant to the wide and random variation of the available electrical power.

Support Vector Regression and ***Random Forest*** have better performance than ***Artificial Neural Networks***. There is not statistical difference significance between Support Vector Regression and Random Forest.

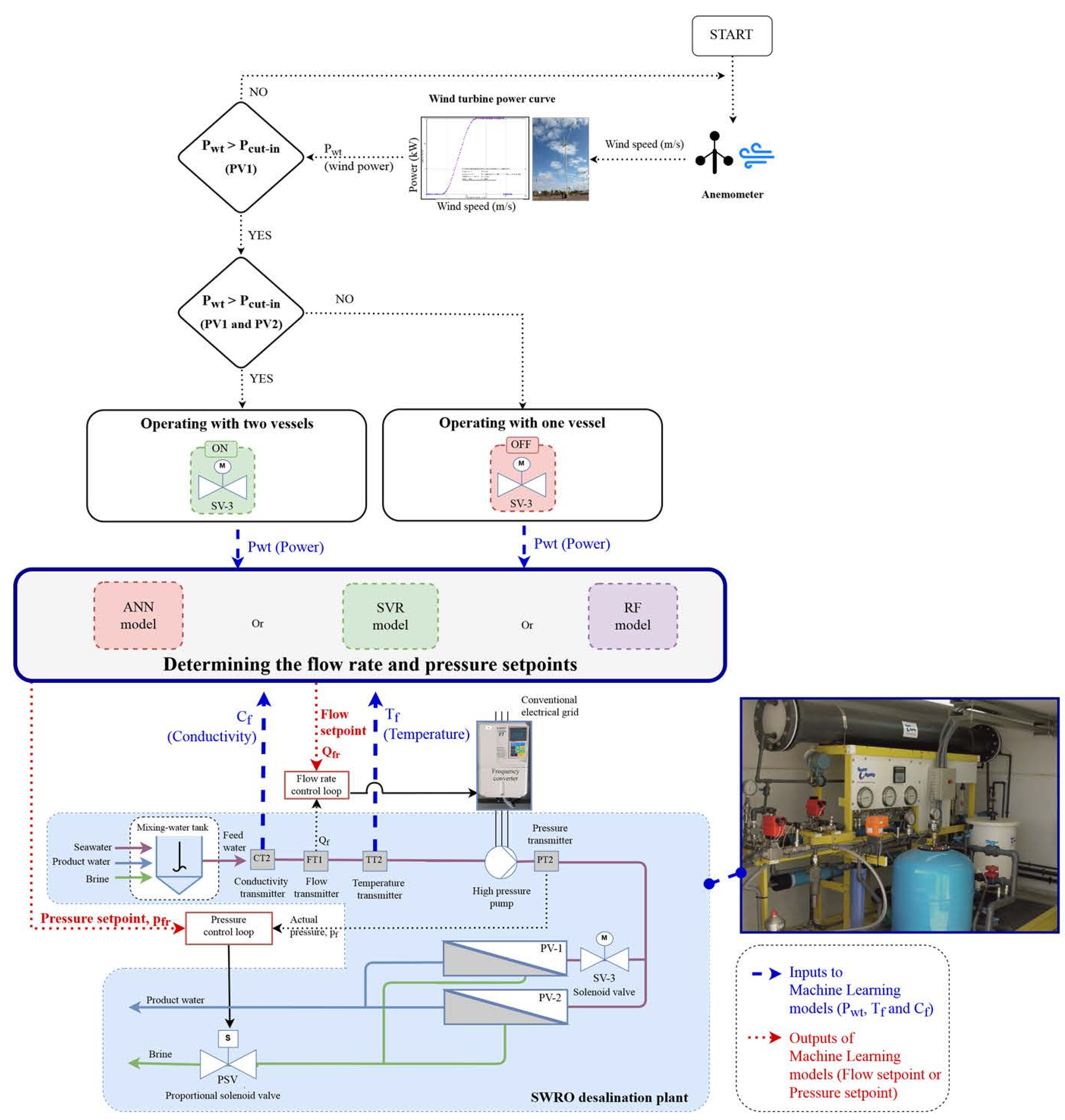

Fig. 2. Layout of the SWRO desalination plant prototype and control system.

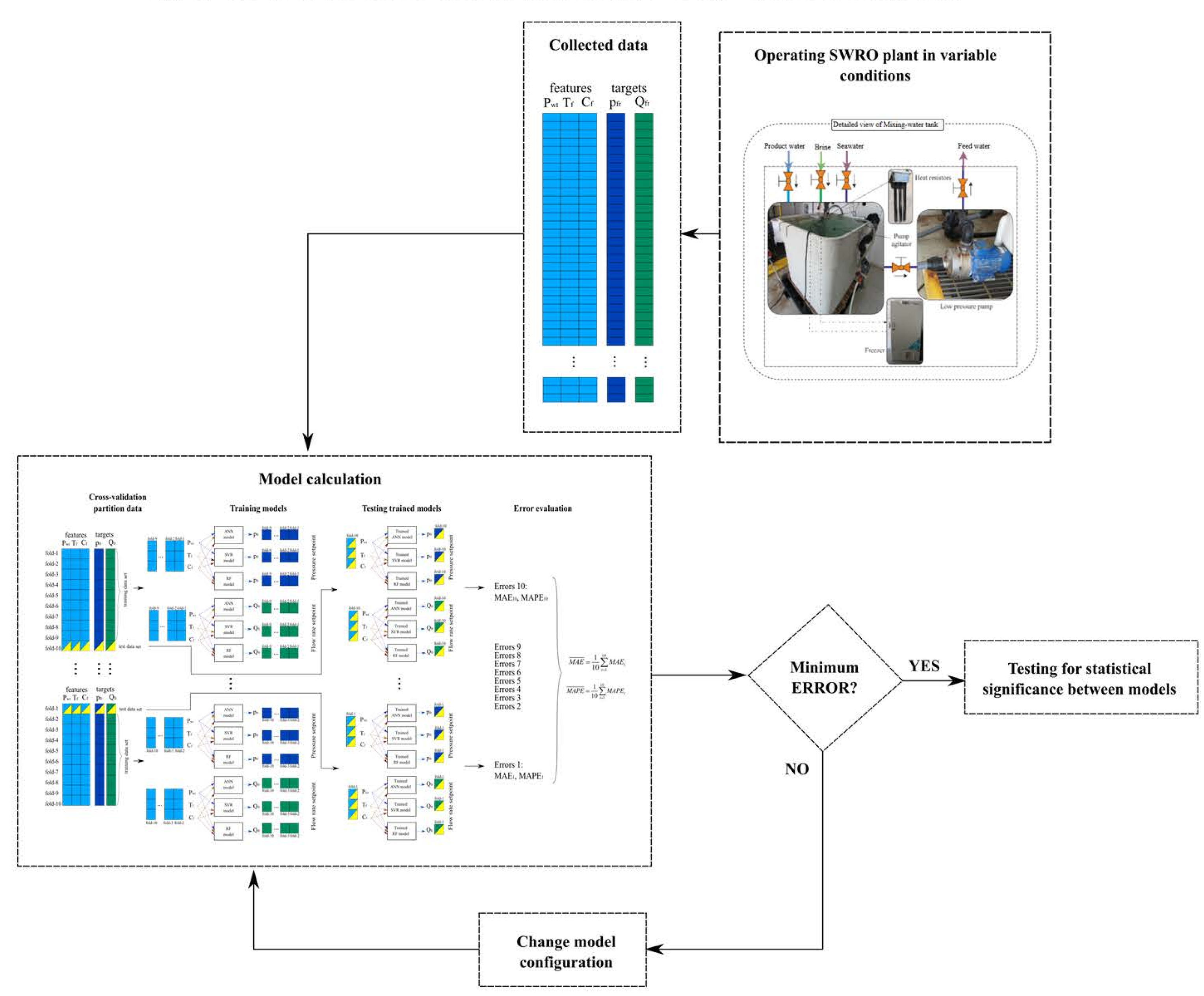

Fig. 3. Block diagram with a schematic representation of the methodology employed in the design and evaluation of the Machine Learning techniques used.

results

Table 1. P-values obtained from comparison of MAE errors of the three ML techniques evaluated.

	PRESSURE		ANN	SVR	RF	FLOW RATE		ANN	SVR	RF
1 vessel		(MAE)	(0.278)	(0.174)	(0.188)		(MAE)	(0.036)	(0.023)	(0.017)
	ANN	(0.278)	-	0.0001	0.0015	ANN	(0.036)	-	0.0010	0.0002
	SVR	(0.174)	0.0001	-	0.8457	SVR	(0.023)	0.0010	-	0.0001
	RF	(0.188)	0.0015	0.8457	-	RF	(0.017)	0.0002	0.0001	-
2 vessels	PRESSURE		ANN	SVR	RF	FLOW RATE		ANN	SVR	RF
		(MAE)	(0.253)	(0.122)	(0.129)		(MAE)	(0.047)	(0.031)	(0.023)
	ANN	(0.253)	-	0.0000	0.0000	ANN	(0.047)	-	0.0000	0.0015
	SVR	(0.122)	0.0000	-	0.8525	SVR	(0.031)	0.0000	-	0.1553
	RF	(0.129)	0.0000	0.8525	-	RF	(0.023)	0.0015	0.1553	-

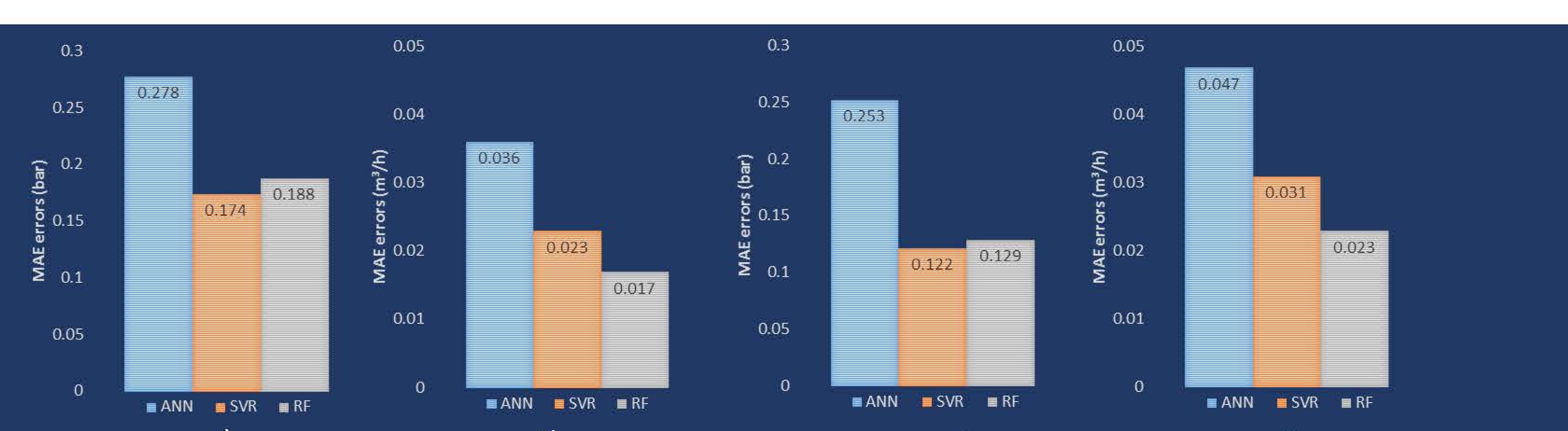

Fig. 4. MAE errors obtained for ML techniques in the estimation of setpoints:
a) Pressure and b) Flow rate, for SWRO desalination plant operating with one pressure vessel; c) Pressure and d) Flow rate, for SWRO desalination plant operating with two pressure vessels.

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