Optimal Drive And Machine Sizing For A Self Starting, Vertical Axis, Low Power Wind Generator

Nicola Bianchi
Silverio Bolognani
Emanuele Fornasiero
Giorgio Pavesi
Mattia Morandin

Electric Drives Laboratory
Department of Industrial Engineering
University of Padova

IEEE - ENERGYCON 2012
International Energy Conference & Exhibition
Florence, Italy, 9-12 September 2012

This presentation refers to the paper

Nicola Bianchi, Silverio Bolognani, Emanuele Fornasiero, Giorgio Pavesi and Mattia Morandin

“Optimal Drive And Machine Sizing For A Self Starting, Vertical Axis, Low Power Wind Generator”

IEEE - International Energy Conference & Exhibition (ENERGYCON 2012)

held in Florence, Italy, 9-12 September 2012

Introduction

The **EDLab is involved in a project**, of the national program **INDUSTRIA 2015**, called **PIACE.** Industria 2015 provides the strategic development and competitiveness of Italian industry of the future. **PIACE** is about domestic cogeneration systems combined with **renewable energies**. It **involves 22 partners** from Universities and Companies, **6** of which **involved on micro wind turbine** topic.

Project idea

Low power wind application for installation in urban areas

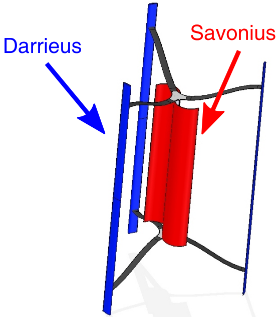
Aim of the study

- Comparison between an **IPM** and an **SPM** generator (with drive) coupled with a **low power wind generator**
- A **Vertical axis wind turbine** is considered:
  - The turbine is omni-directional
  - Darrieus turbine coupled to a Savonius turbine to realize a self–starting turbine
- A **cost analysis** has been done to the aim of **evaluating the convenience of the system** in terms of total profit and pay–back time

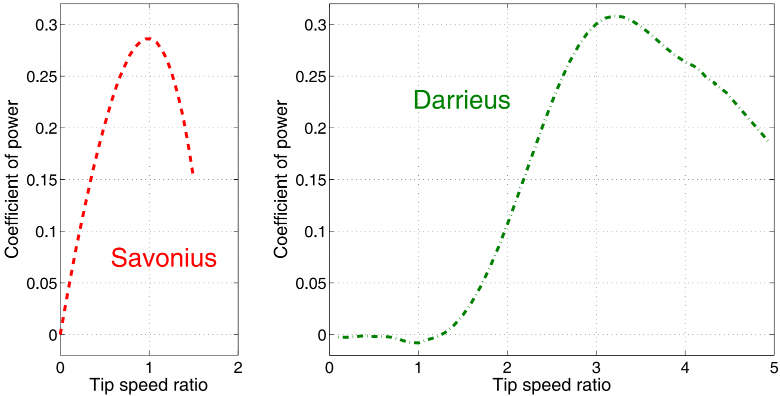
Combined wind turbine

The combined turbine is constituted by:

- **Savonius** turbine (diameter of 0.3m)
- **Darrieus** turbine (diameter of 1.9m and height of 3m)



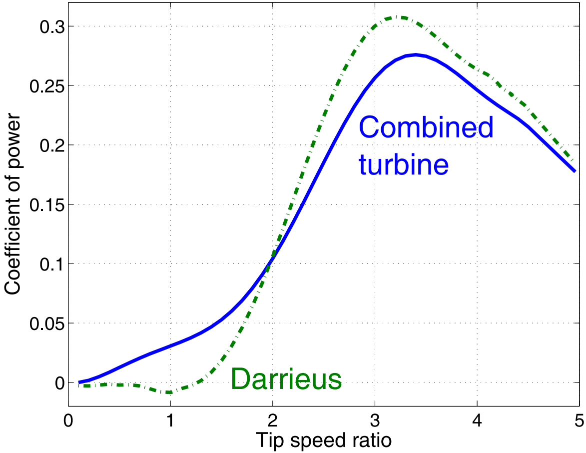
Combined wind turbine



Tip speed ratio

$$\lambda = \frac{D_t \ \omega_m}{v_{wind}}$$

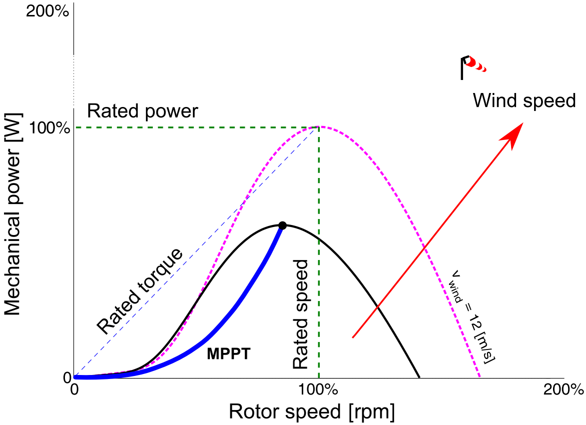
Combined wind turbine



Optimization criteria

Reference case

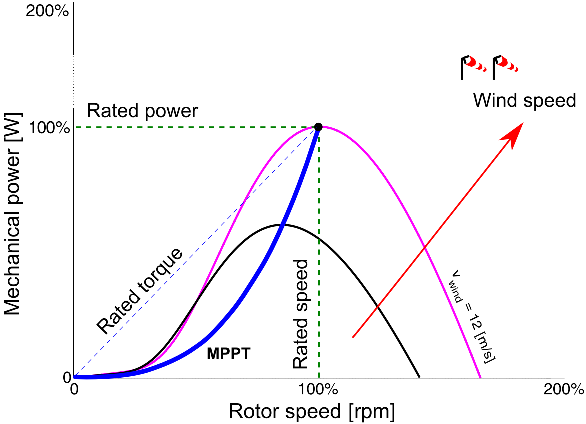
MPPT until $v_{wind} = 12 m/s$, then **stall**



Optimization criteria

Reference case

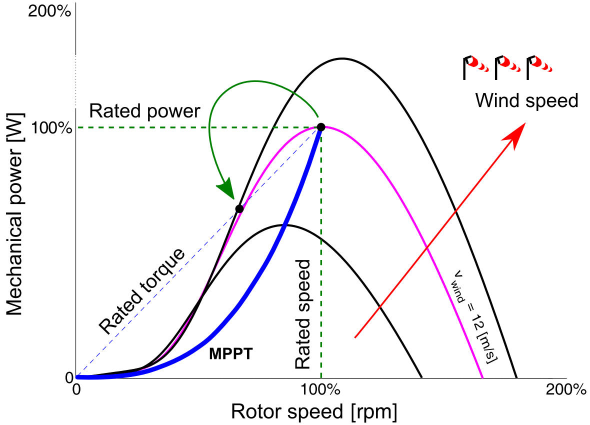
MPPT until $v_{wind} = 12 m/s$, then **stall**



Optimization criteria

Reference case

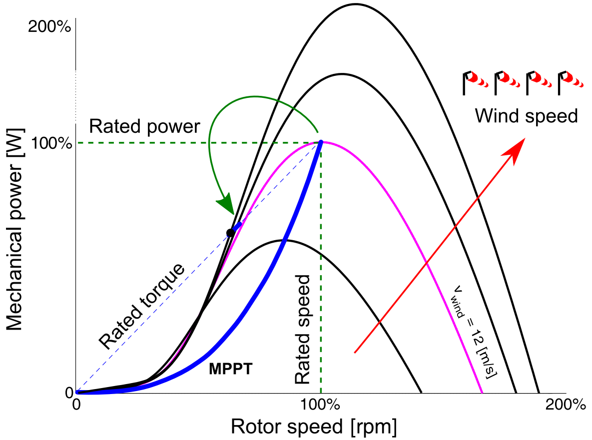
MPPT until $v_{wind} = 12m/s$, then **stall**



Optimization criteria

Reference case

MPPT until $v_{wind} = 12m/s$, then **stall**



Optimization criteria

Reference case:

- Rated power: 1650W
- Rated torque: 39Nm
- Rated speed: 405rpm

In order to optimize the design, some **limitations** can be introduced to reduce the initial cost of the system

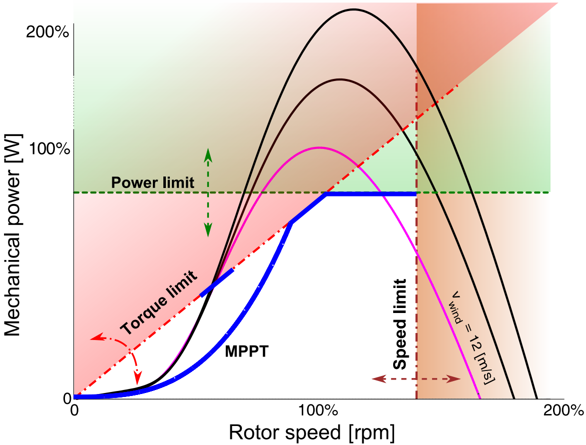
Combination of:

- Power limit
- Torque limit
- Speed limit

The **maximum profit**, without penalizing the **payback–time**, is chosen as the optimization objective.

Optimization criteria

- Example of application of the limits



Optimization criteria

Assumptions:

- **Weibull statistics** used as base for wind probability: parameters $k = 1.4$ and $v_{avg} = 4.5\ m/s$
- **MPPT tracking** algorithm to maximize the power up to $v_{wind} = 12m/s$
- **Mechanical brake** to stop the turbine at maximum speed ($v_{wind_{max}} = 15m/s$)
- Estimated efficiency of 90% for both generator and converter

- The proposed analysis can be promptly arranged for any different system parameters

Optimization criteria

Assumptions for cost analysis:

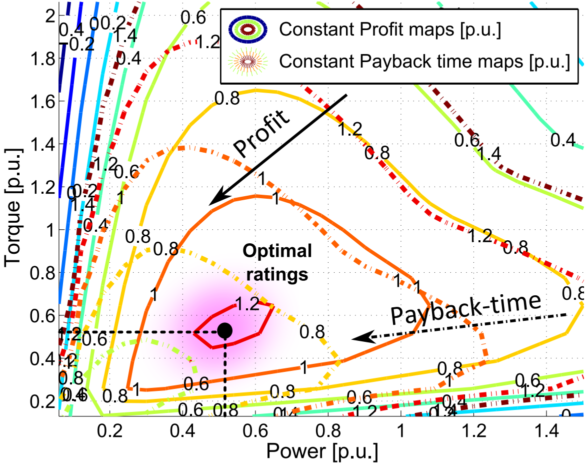
- Energy remunerated for 10 years;
- **Electric generator cost** $\propto$ rated torque
- **Power converter cost** $\propto$ rated power
- **Turbine mechanical cost** $\propto$ maximum torque $\times$ maximum speed

$\Rightarrow$ Initial cost:

$$C_{initial} = c_{gen} T_{max} + c_{el} P_{max} + c_{mec} T_{MPPT} n_{max}$$

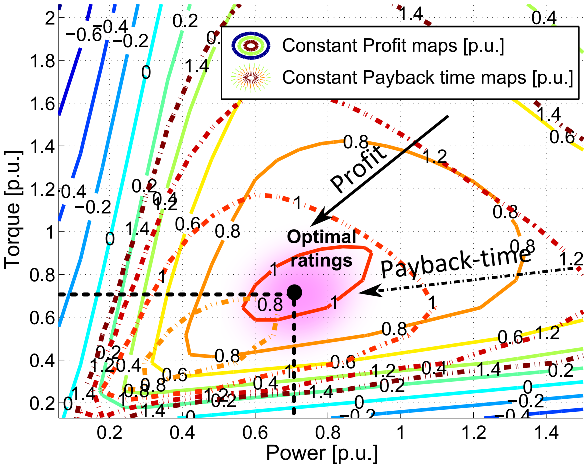
index cost	*price*	*unit*
p_e	0.4	€$/kWh$
c_{gen}	22	€$/Nm$
c_{el}	0.6	€$/W$
c_{mec}	0.04	€$/(Nm * rpm)$

IPM optimization result



Maximum rotor speed: 185% of reference case

SPM optimization result



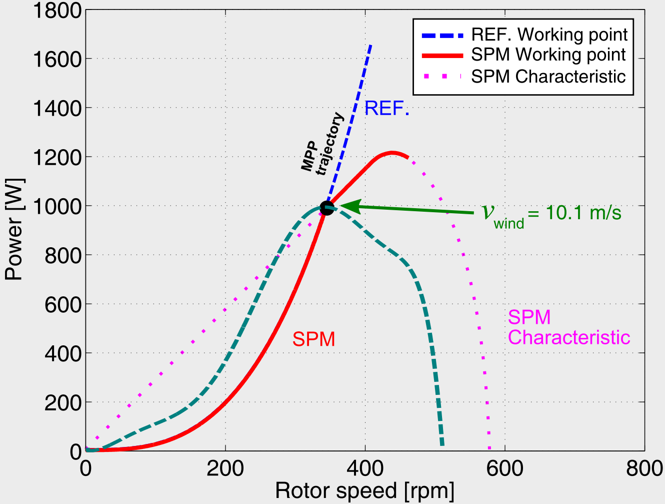
Maximum rotor speed: 120% of reference case

Economical results

	Reference machine	Optimized SPM	Optimized IPM	Unit of measure
Best torque	–	70	50	% T_{ref}
Best power	–	70	50	% P_{ref}
Best speed	–	120	185	% ω_{ref}
System price	2.50	1.87	1.63	[k€]
Total profit	2.10	2.22	2.51	[k€]
Payback time	5.42	4.57	3.94	[years]

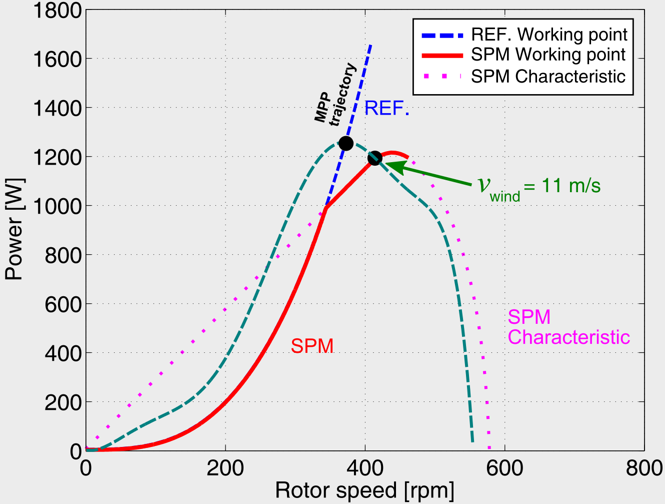
SPM working points

Power vs speed



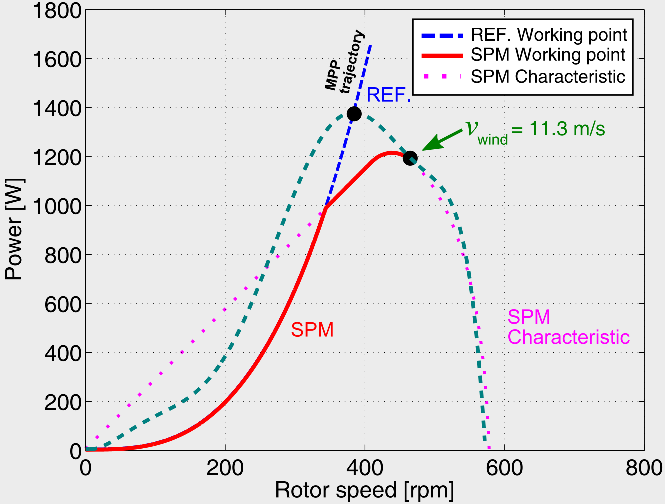
SPM working points

Power vs speed



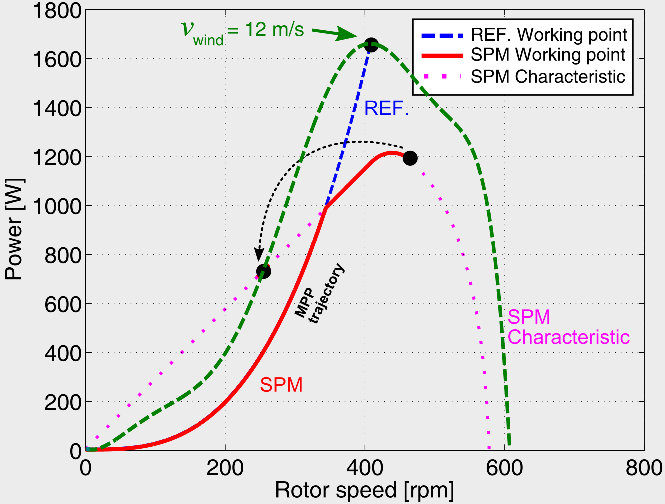
SPM working points

Power vs speed



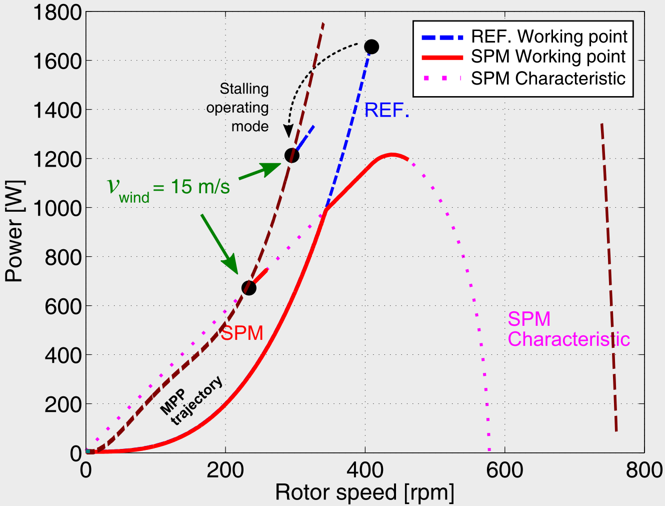
SPM working points

Power vs speed



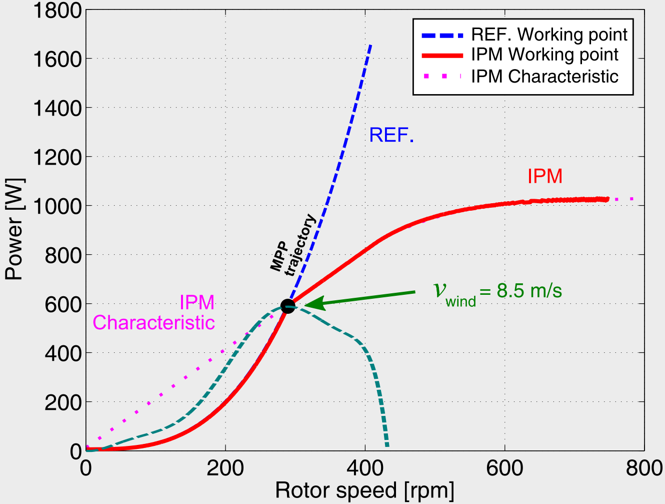
SPM working points

Power vs speed



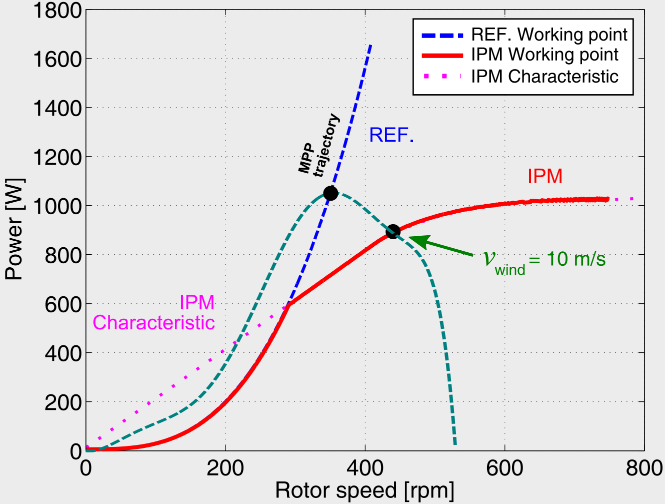
IPM working points

Power vs speed



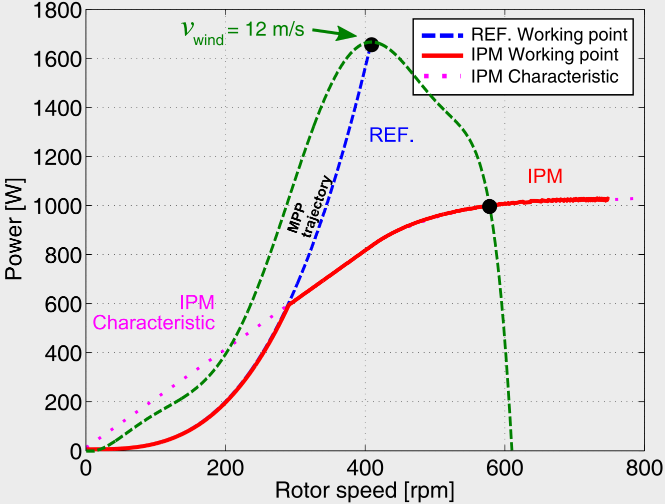
IPM working points

Power vs speed



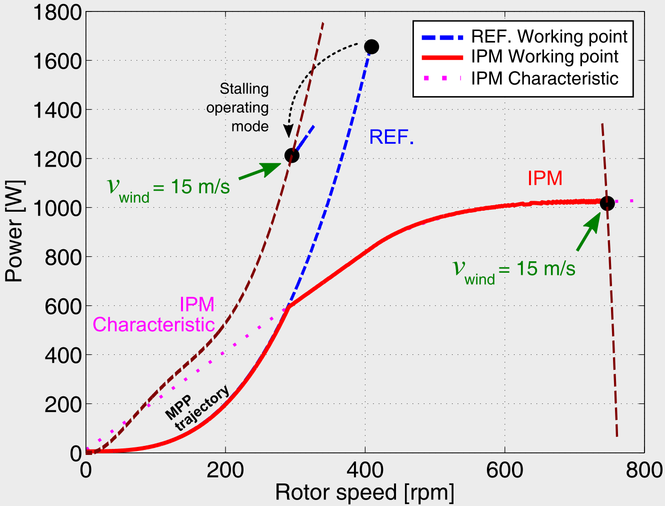
IPM working points

Power vs speed

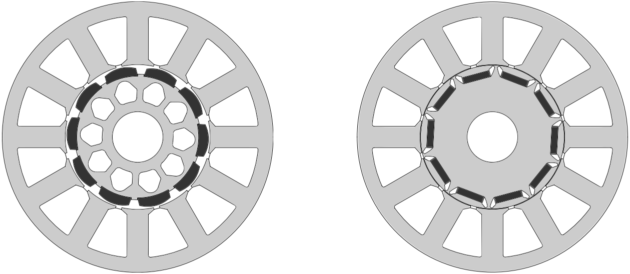


IPM working points

Power vs speed



Machine design



	SPM	IPM	Unit
Air–gap diameter	71	71	[mm]
External diameter	133.5	133.5	[mm]
Stack length	118	95	[mm]
Slot current density	6	6	[A_{rms}/mm^2]
Rated torque	28	19	[Nm]
Base speed	415	415	[rpm]
PM weight	0.645	0.3	[kg]
Iron weight	7.5	7.2	[kg]
Copper weight	2.25	1.91	[kg]
Total weight	10.4	9.4	[kg]

Conclusions

- An economical comparison have been proposed for two cases of low power wind generator applied to a VAWT: a SPM and an IPM machine
- Torque, power and speed limits have been introduced to reduce the initial cost of the whole system
- Both the cases of study present an improvement in terms of cost of the system, compared with the cost of the reference case (i.e without the above limits)
- Even if there is a loss of energy productivity, an optimal solution can be found, which maximizes the profit with a reduced payback time.
- An effective profit–payback time chart is proposed to point out the optimal solution.

Related Papers by the Authors

- N. Bianchi and A. Lorenzoni,
  "Permanent magnet generators for wind power industry: an overall comparison with traditional generators," in *International Conference on Opportunities and Advances in International Electric Power Generation*, Mar. 1996, pp. 49–54.
- M. Morandin, E. Fornasiero, S. Bolognani, and N. Bianchi,
  "Torque/power rating design of an ipm machine for maximum profit-to-cost ratio in wind power generation," in *Electric Machines Drives Conference (IEMDC), 2011 IEEE International*, may 2011, pp. 1113 –1118.

Related Papers by the Authors (cont.)

N. Bianchi and S. Bolognani,
“Parameters and volt-ampere ratings of a synchronous motor drive for flux-weakening applications,” *IEEE Transactions on Power Electronics*, vol. 12, no. 5, pp. 895 –903, sep 1997.

Thank you for your attention