KiteGen: a Revolution in Wind Energy Generation

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Need of a "quantum leap" in renewable energy technologies

- About 80% of word electric energy is produced from fossil sources
- Problems of fossil sources:
  - Increasing costs (demand of developing countries, sources shortage)
  - Environmental impact (pollution, climate changes)
  - Geopolitical implications
- The most optimistic forecasts on diffusion of present renewable technologies (wind, photovoltaic, biomasses) estimate to reach within next 15-20 years a level of 20% of contribution to total electric energy production

Need of a "quantum leap" in renewable energy technologies

- Wind turbines are currently the largest sources of renewable energy (excluding hydroelectric plants)
- Problems of wind farms:
  - Large costs due to heavy towers and foundations
  - Large territory occupation (up to 200-300 times a thermal plant of the same power)
- Aim of the project:
  - design and build KiteGen, a new type of wind generator able to overcome these drawbacks
  - demonstrate that KiteGen technology can contribute in few years large % of electric energy generation

KiteGen project

- **Partners:**
  - **Dipartimento di Automatica e Informatica, Politecnico di Torino**
  - **Sequoia Automation srl, Chieri**
  - **Modelway srl, Incubatore Imprese Innovative del Politecnico di Torino**
  - **Centro Studi Industriali sas, Milano**
  - **Azienda Energetica Metropolitana Torino spa**

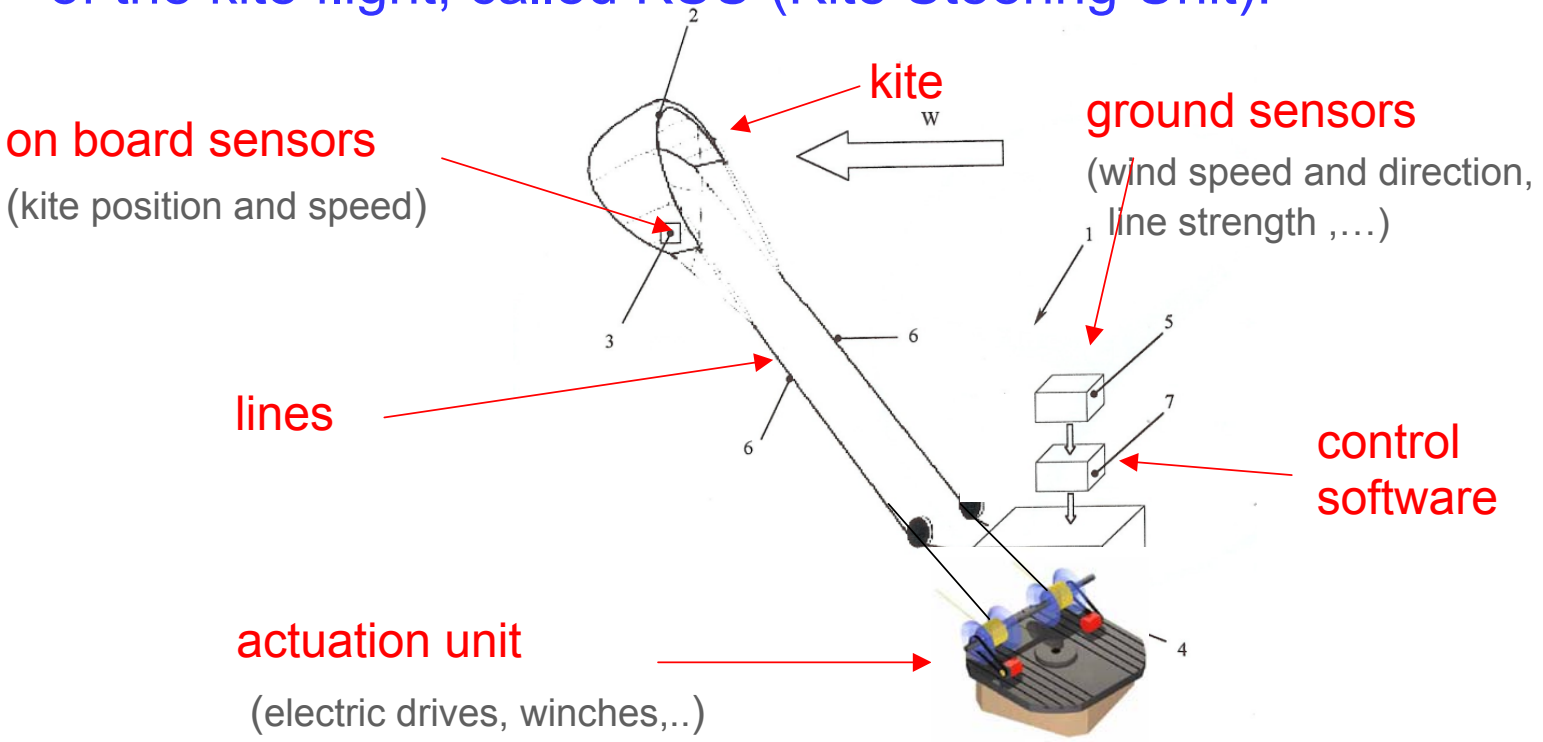
KiteGen: wind energy from controlled tethered airfoils (kites)

- Expert kite-surfers are able to drive the kites in order to generate the energy for the navigation

- They act on the lines according to:
  - wind
  - kite position and speed
  - desired motion
  - ……

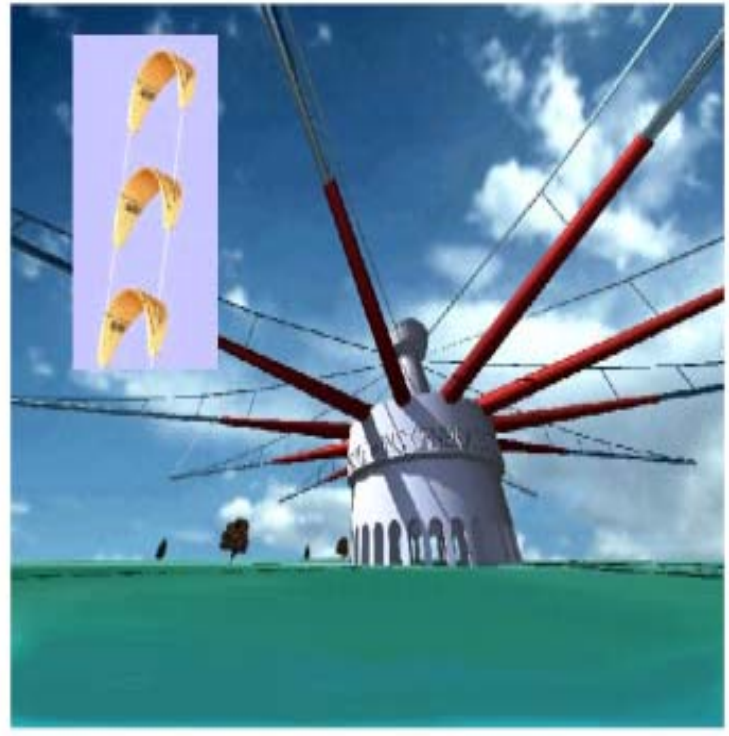
Control unit of kite flight

- The core of KiteGen is the system of automatic control of the kite flight, called KSU (Kite Steering Unit):



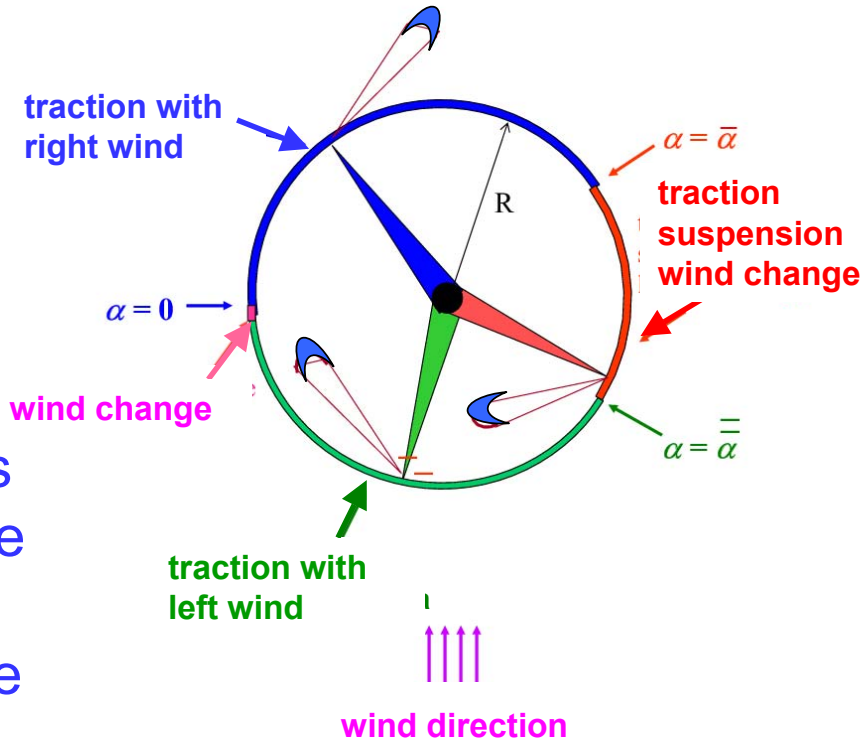
KiteGen carousel configuration

- Each KSU is connected to the arms of a vertical axis turbine
- The control system is designed to drive the flight of the kites in order to rotate the turbine and maximize the exerted torque
- The turbine transmits the rotation to an electric generator
- The torque opposed by the electric generator is controlled to have constant rotation speed



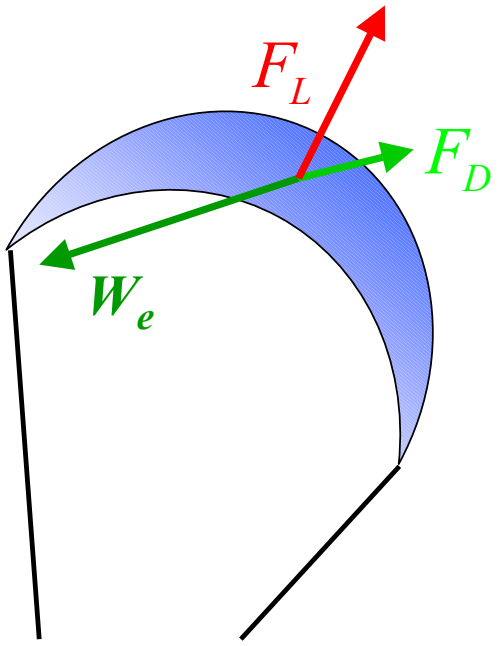
KiteGen carousel configuration

- Energy is generated in periodic cycles composed of 4 phases:
  - **traction with right wind**
  - **traction suspension and wind change**
  - **traction with left wind**
  - **wind change**
- Control system maximizes the power generated in the traction phases and minimizes the power in the passive phases



Kite modeling and control techniques

- A MPC (Model Predictive Control) method is used based on a aerodynamic model of kites



$$F_L = \frac{1}{2} C_L A \rho |W_e|^2$$

$$F_D = \frac{1}{2} C_D A \rho |W_e|^2$$

W_e : velocità kite rispetto al vento

A : area kite

$\rho = 1.2$

$E = C_L / C_D$ ← Efficienza aerodinamica

Kite modeling and control techniques

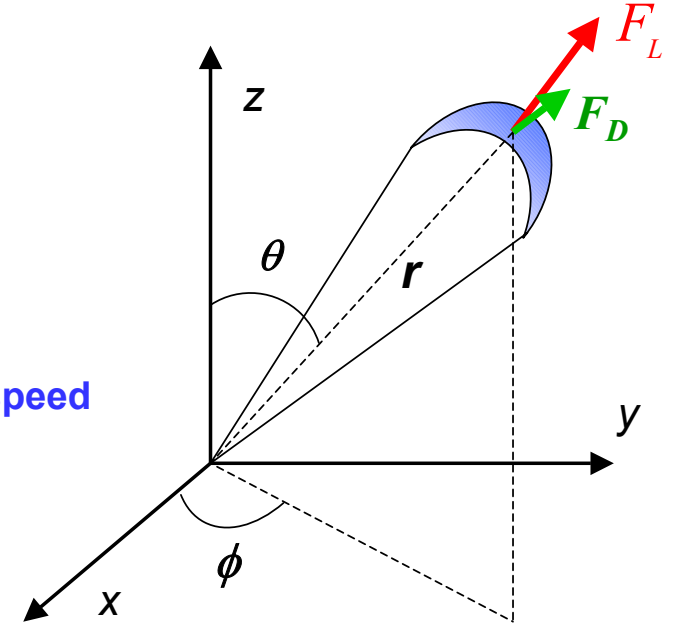
- Model equations are of the form:

$$\dot{x} = g(x, u, W_w)$$

kite position and speed in spherical coordinates θ, ϕ, r

differential length of lines

wind speed



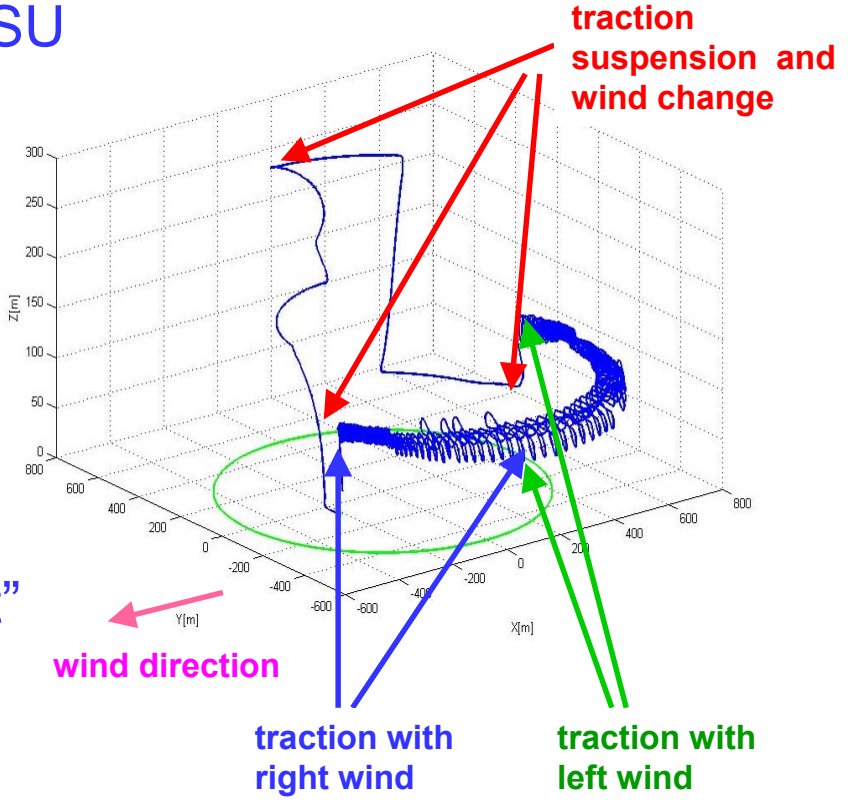
Spherical coordinate system

KiteGen carousel configuration: how much energy can be generated ?

- The generated power depends:
  - linearly with kite area A
  - with the cube of the wind speed W_e
  - with the square of aerodynamic efficiency $E = C_L / C_D$

KiteGen carousel configuration: how much energy can be generated ?

- Simulation of a single KSU
  - kite area A= 100 m^2
  - kite efficiency ***E= 8***
  - wind speed W_e ***= 12 m/s***
  - turbine radius ***R= 300 m***
- The turbine rotates at ***0.13 rpm,*** with tangential speed of ***5 m/s (18 km/h)***
- The kite flies "lying eight" at high speed (around ***200 km/h***)



KiteGen carousel configuration: how much energy can be generated ?

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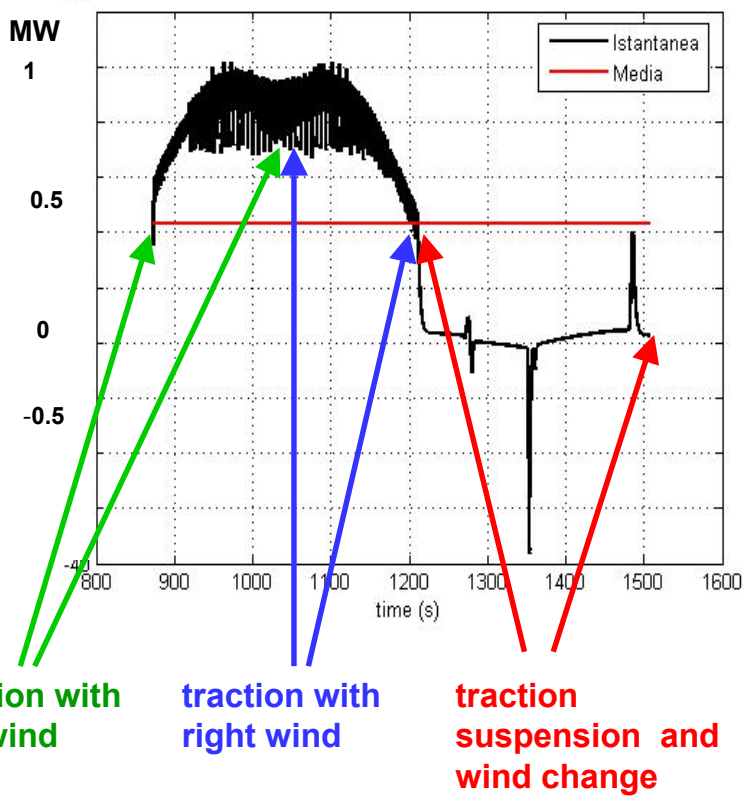
generated mean power:
400 KW



KiteGen carousel configuration: how much energy can be generated ?

- A single KSU with:
  - kite area $A = 500\ m^2$
  - kite efficiency $E = 12$
  - wind speed $W_e = 12\ m/s$

→ 8 MW mean power

- 60 such KSU moving on carousel with $R = 1500\ m$:

↓

1000 MW KiteGen

Will KiteGen be a quantum leap over present wind farm ?

	KiteGen *1000 MW*	Wind farm *1000 MW*
➢ **Territory occupation**	*5-6 Km²*	*250-300 Km²*
➢ **Production cost** (MW*h)	*5.0 €*	*140 €*

KSU prototype

- A KSU prototype has been realized with the partial support of Regione Piemonte
- At present it is used to:
  - test accuracy of models used in simulation analysis
  - derive from experimental data more accurate models of kite aerodynamic (if required)
  - test the designed control
  - experimentally verify the generated power predicted in simulation

KSU prototype

KSU prototype flight tests

KSU prototype flight tests

KSU prototype flight tests