Tandem Bicycle Analogy

Source: http://www.leonardo-energy.org/

The electrical system as a tandem bicycle

- Electrical system =
  - crucial part of everyday economy
  - highly complex

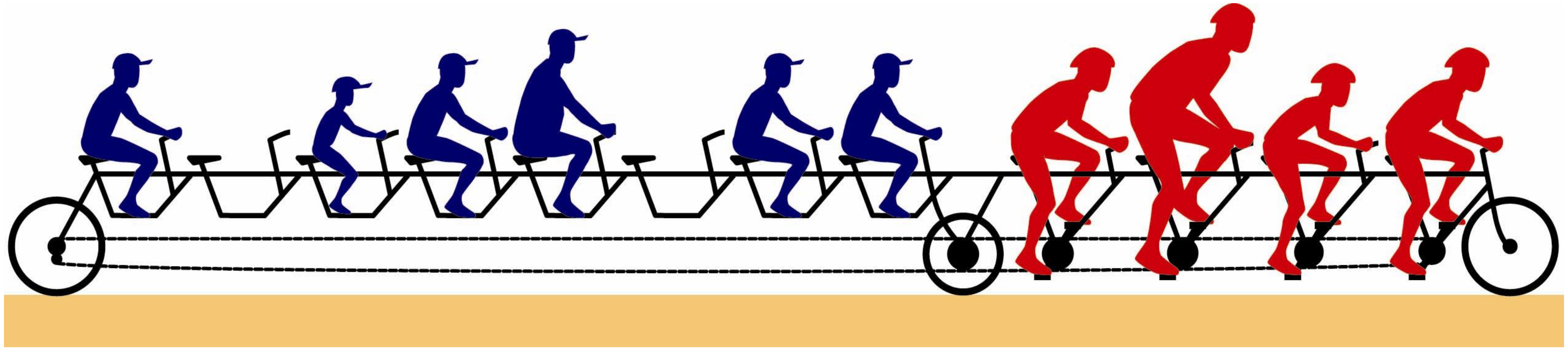
→ A good analogy to form a better idea of how things work

→ Comparison with a tandem bicycle

The electrical system as a tandem bicycle

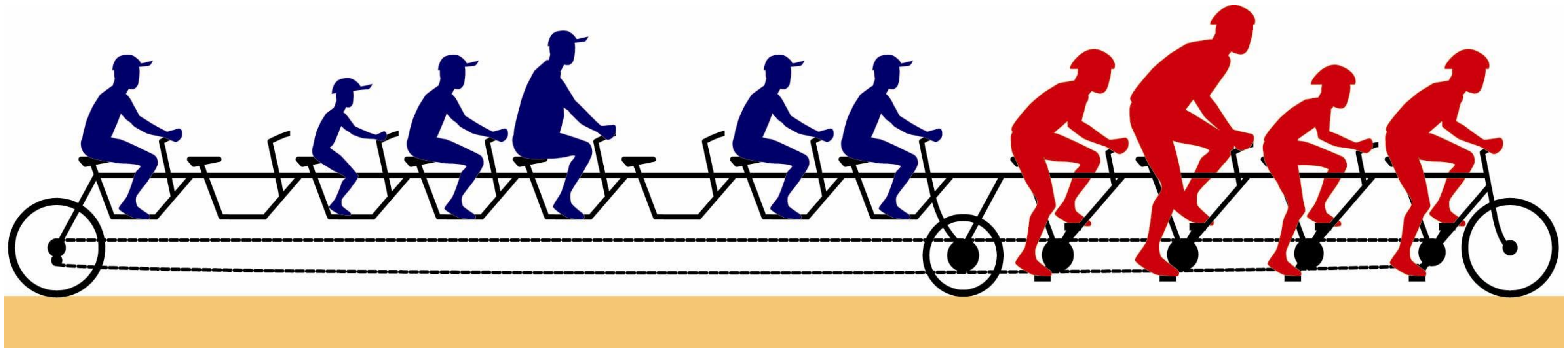
- No analogy is a 100% fit
  - Not all characteristics can be "translated"
  - Certain aspects of the analogy are not completely accurate
- Similarities are close enough
- Of great help in understanding the abstract electrical system

The basic representation of the system



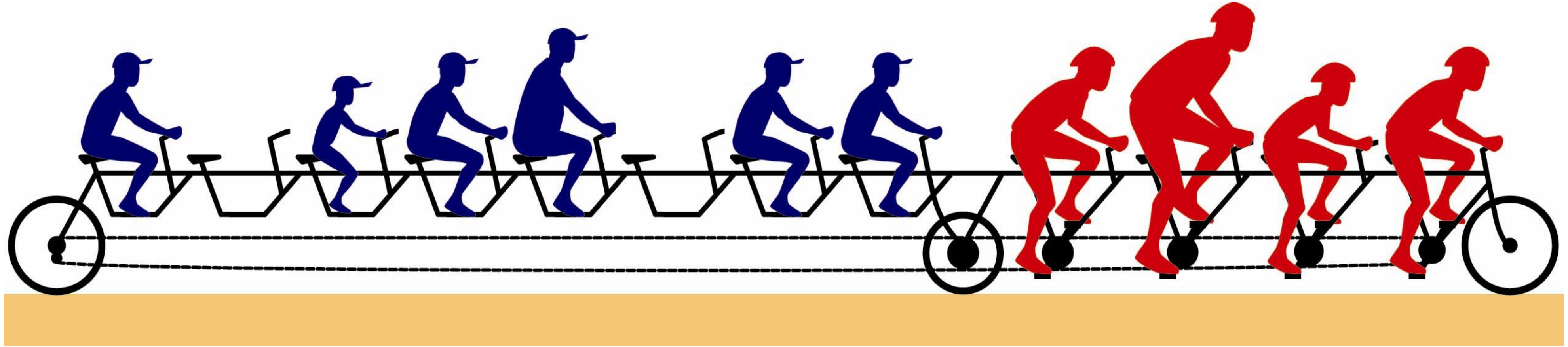
- Tandem bicycle moving at constant speed
- Goal: keep the blue figures moving
- Blue figures = load (industrial loads, private dwellings)
- Red figures = power stations (different sizes)

The basic representation of the system



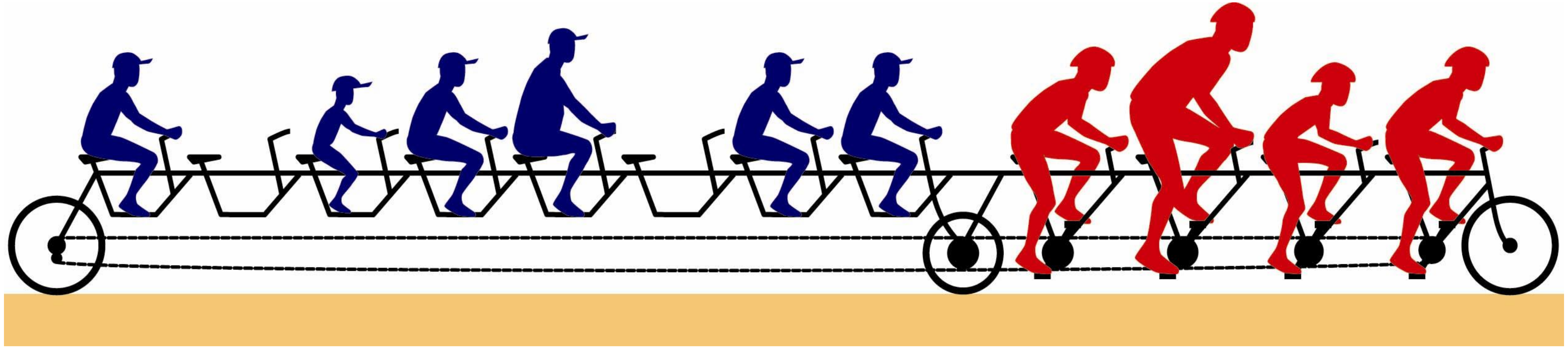
- Chain = electrical network
- Chain must turn at constant velocity (electrical network must have a constant frequency)
- Upper part chain must be under constant tension
  (an electrical connection should have constant voltage level)

The basic representation of the system



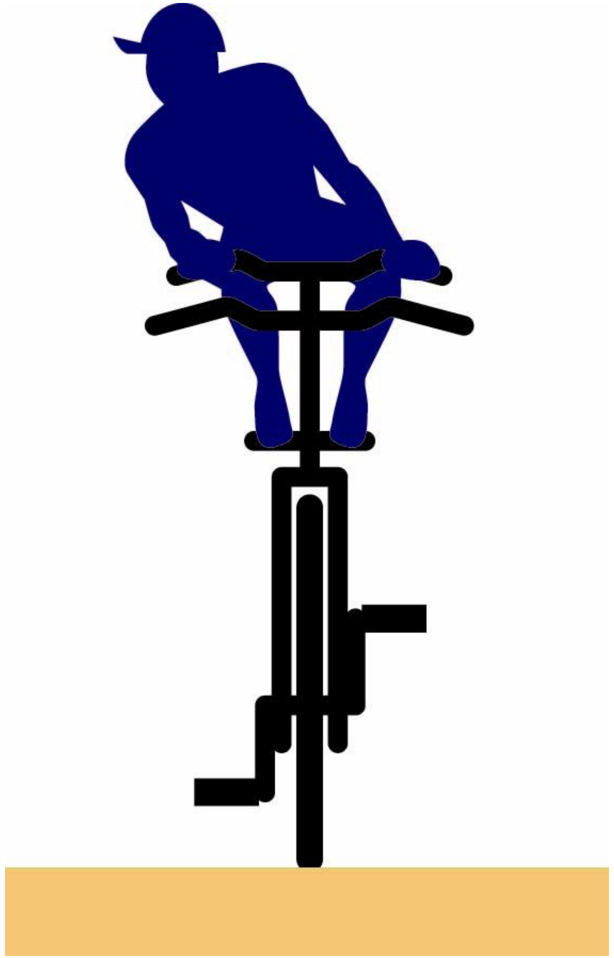
- Lower part chain, without tension = neutral wire
- Gear transmitting energy to chain = transformer connecting power station and electrical network

The basic representation of the system



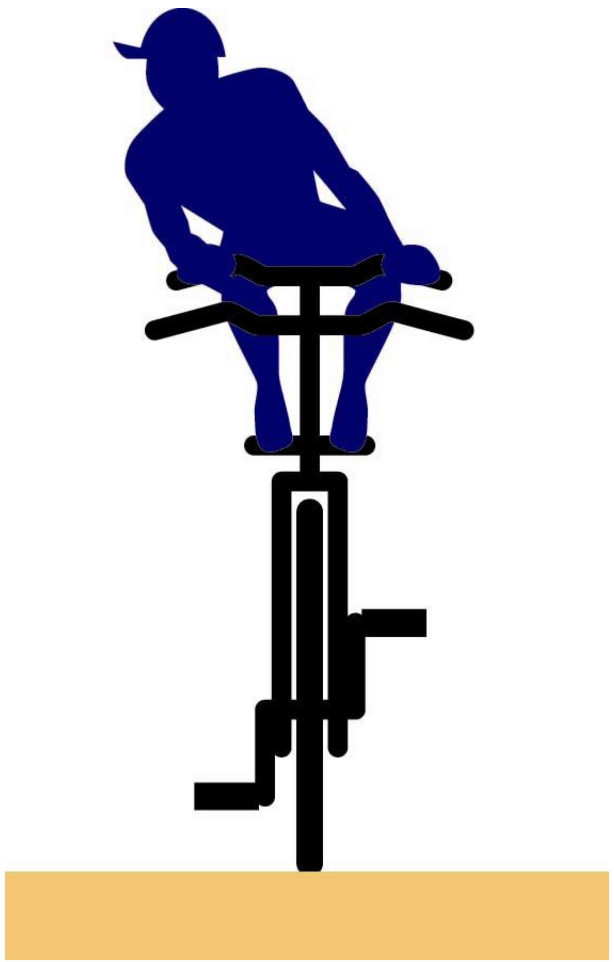
- Some red figures (power stations) don’t pedal at full power
- They’re able to apply extra force when
  - Another blue figure (load) jumps on the bike
  - One of the red figures (power stations) gets a cramp (= technical problems)

Inductive power and its compensation



- Blue figure leaning to one side = inductive load
- Inductive load has shifted sinus wave (more specific: a delayed sinus)
- Origin: electrical motor induction coils, fluorescent lighting ballasts, certain types of electrical heating…

Inductive power and its compensation



- Blue figure:
  - Normal weight (= normal load)
  - No influence on chain tension (= normal voltage level)
  - No influence on velocity (= normal frequency)
- But without compensation, bike might fall over

Inductive power and its compensation

- Red figure leaning in opposite direction to compensate

  = power station generating inductive power (power with a shifted sinus, just like load)

Inductive power and its compensation

- Consequences:
  - Compensation has to be immediate and exact, requiring clear understanding
  - Pedalling figure leaning to one side can't work as comfortably as before
  - Bike catches more head wind, leading to extra losses

Inductive power and its compensation

- Better: compensate close to the source by a capacitive load

  = blue figure sitting close to inductive load but leaning to opposite side

- Capacitive load has sinus with lead time, compensating for delay in sinus of inductive load

Harmonic distortion (1)

- Hyperactive blue rider
  - Bending forward and backwards
  - Three or five times faster as rhythm of bike

  = Harmonic load

- Origin: TV sets, computers, compact fluorescent lamps, electrical motors with inverter drives…

Harmonic distortion

- Should be compensated close to source, if not
  - → bike starts to jerk forward and backwards
  - →extra energy losses

- Compensated by harmonic filter
  - = saddle mounted on castors that moves forward and backwards, neutralizing hyperactive blue rider

Keeping constant voltage and frequency

- Slippery shoes (= failure in power station)

→Shoe slips off pedal (= power station is shut down)

→Tension on chain drops

= voltage dip on grid

→ Risk of hurting himself, since pedal keeps on turning (= risk of damaging pieces during immediate shut down)

Keeping constant voltage and frequency

→Needs to be compensated for by other pedallers, or velocity will drop

= Other power stations should raise their contribution, or frequency will drop

Keeping constant voltage and frequency

→Risky to put foot on turning pedal again

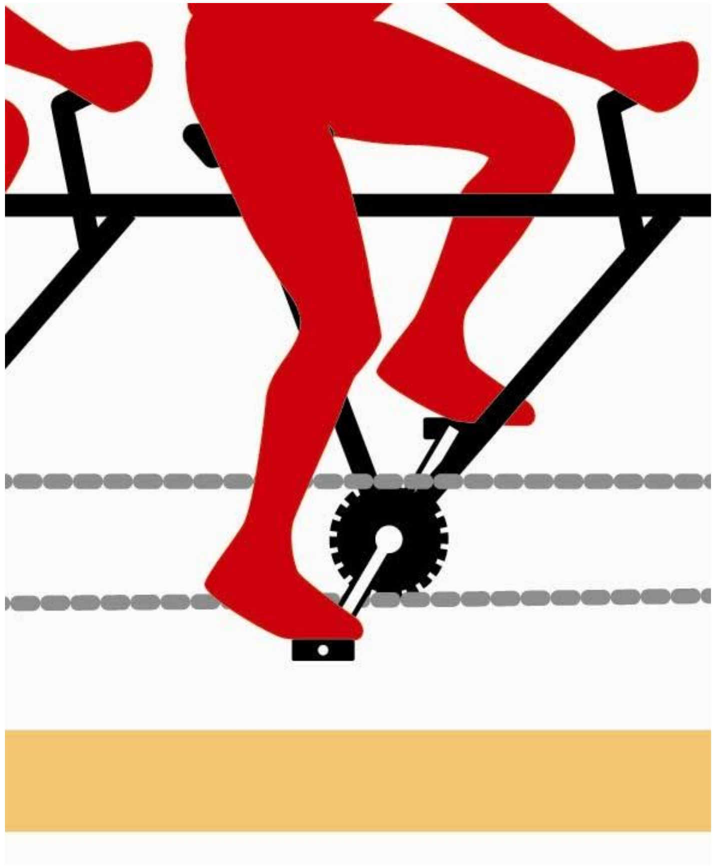
= tricky operation to reconnect power station to network, since frequencies have to match

Keeping constant voltage and frequency

- Similar voltage dip possible when heavy load is suddenly connected (blue rider jumps on bike)

- A heavy load suddenly disconnected (blue rider jumps off bike) → a voltage peak can occur

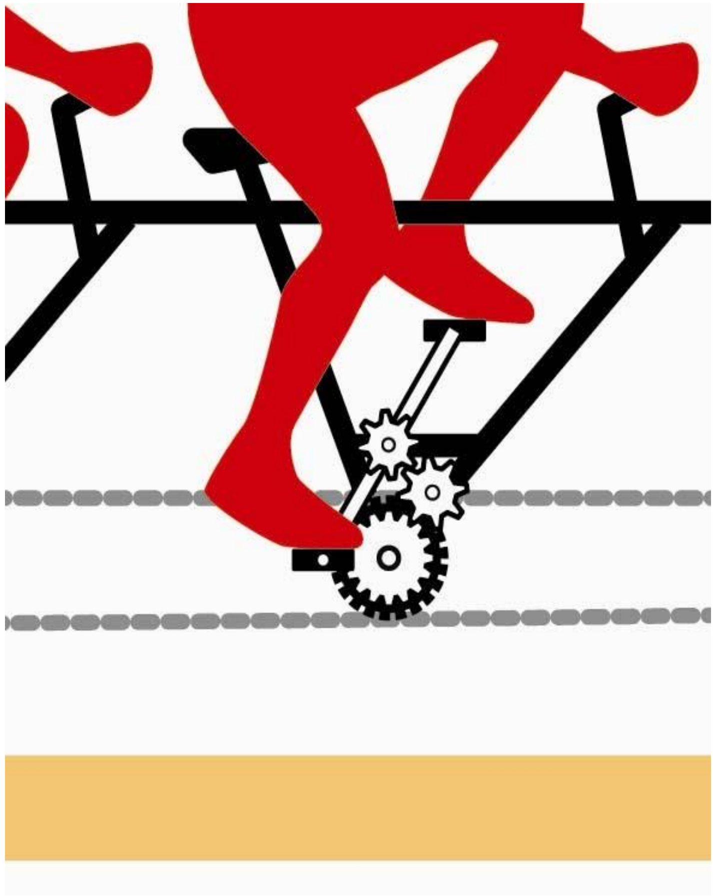
Three different types of power stations



→Red figures, connected to chain by one gear and peddling at constant speed

= large traditional power stations, turning at constant speed and connected to network by transformer

Three different types of power stations

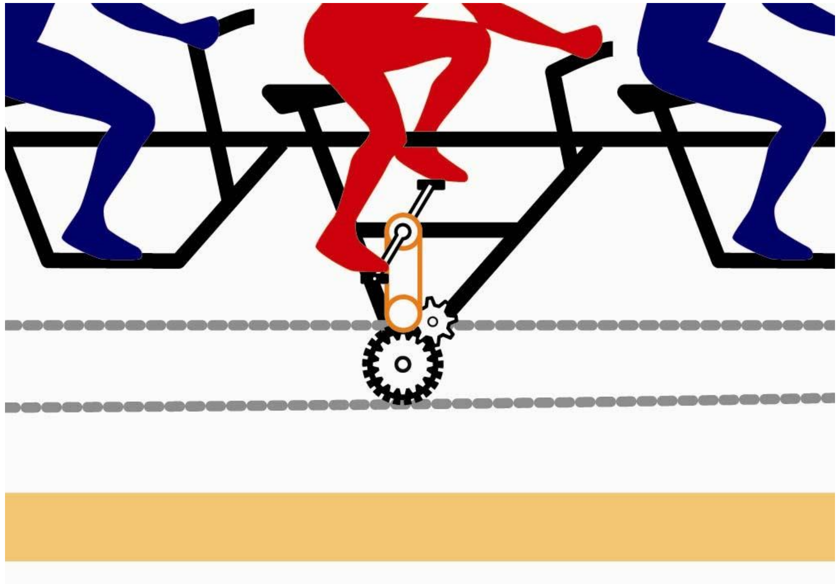


- Biker who can pedal slower
- Connected to chain by gear system

= Hydro turbine, speed depending on flow of river

- Turbine connected to generator by gear system
- Or: generator connected to network by frequency inverter

Three different types of power stations

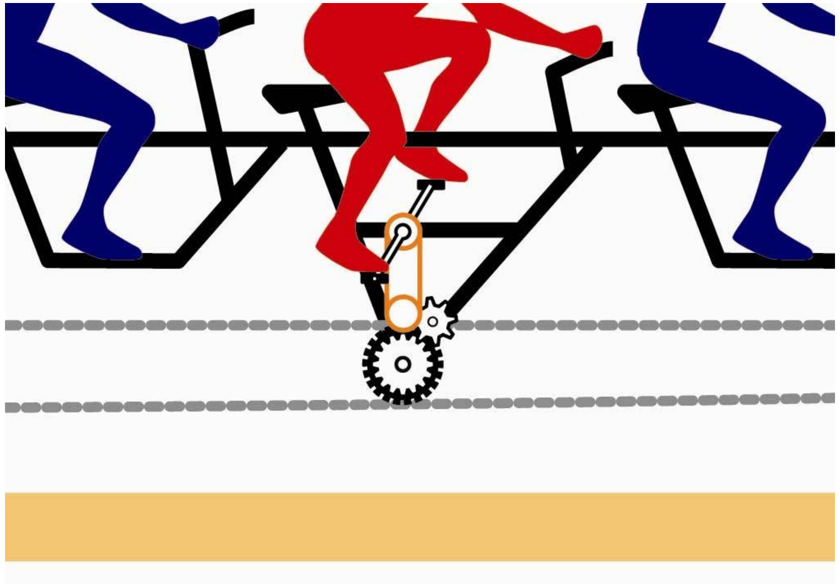


- Small red figure
- Pedalling only when the weather is nice
- Other bikers can't rely on him

= wind turbine

- Functioning when wind speed is not too slow and not too fast
- Back up of other power stations necessary

Three different types of power stations

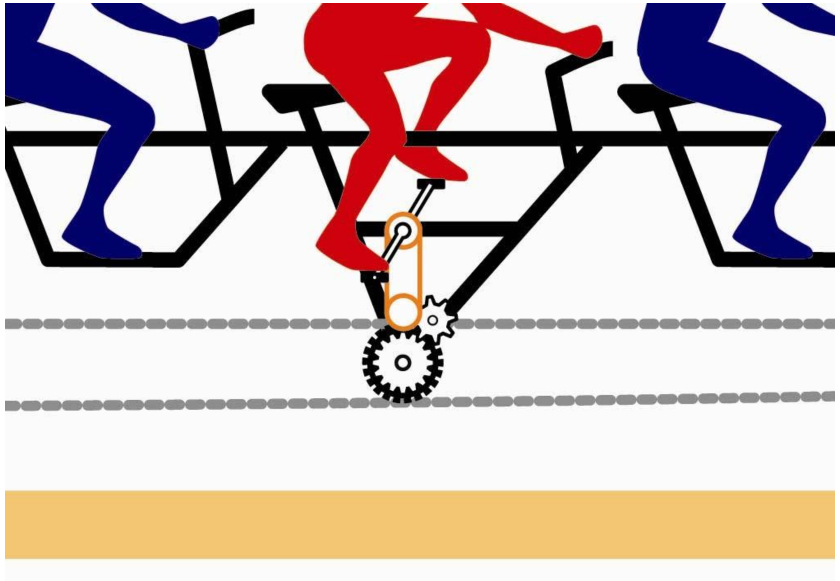


- Connected by belt and gear system

= wind turbines, connected by gear box or frequency inverter to cope with varying wind speed

- Why a red rider between blue riders?

Three different types of power stations



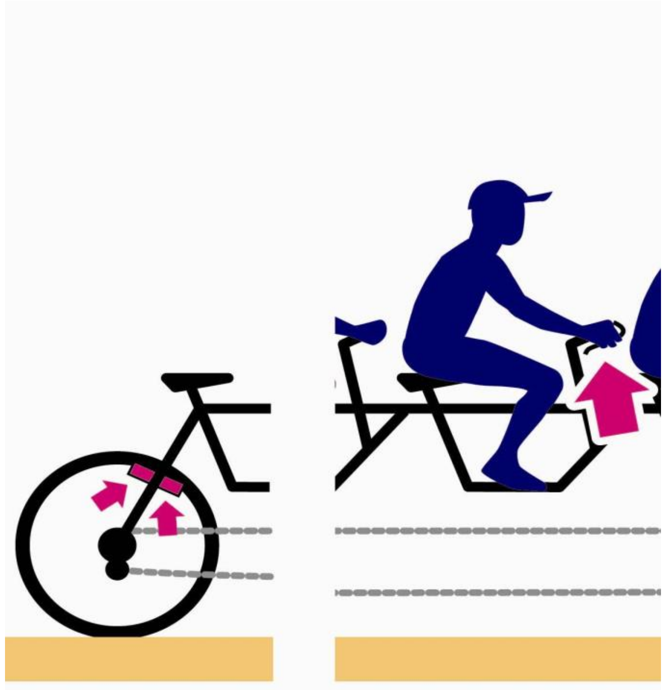
- Why between blue riders?

1) Wind turbines are much smaller than traditional power stations

2) Wind turbines usually not connected to high voltage grid like other power stations, but to distribution grid

→ Since this grid is designed for serving loads, dispatching and grid protection become complex

Three different types of loads



- Blue rider without pedals, pulling brakes

= electrical resistance

- E.g.: light bulbs, most types of electrical heating systems

- Brakes transform kinetic energy into heat
- Just like a resistance transforms electrical energy into heat

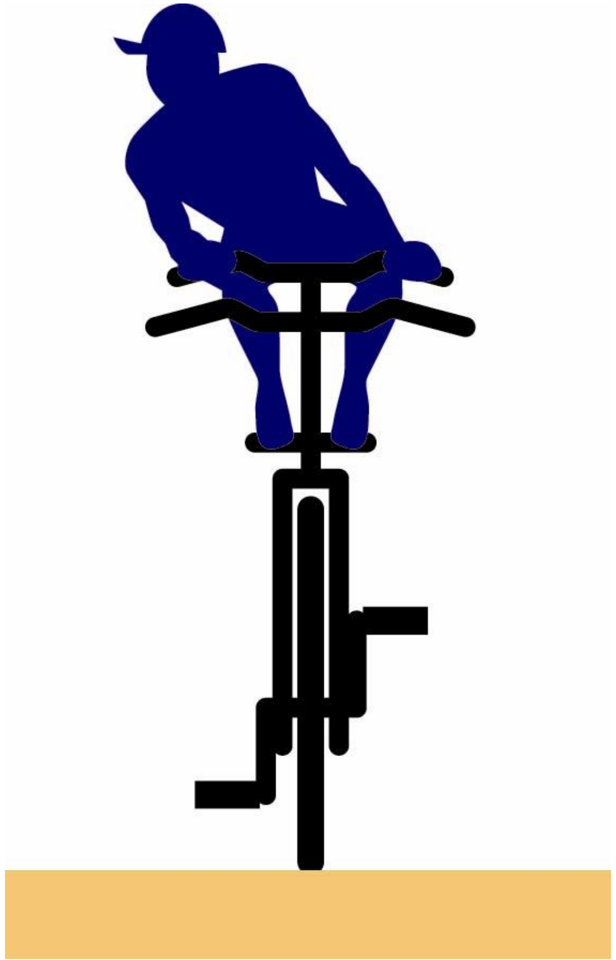
Three different types of loads

- Blue rider, feet on turning pedals
- Instead of making pedals move, he applies his full weight against the rotating movement, so that pedals *are moving him*

= An electrical motor

- Same basic principle as generator
- Transforming electricity into rotating movement, instead of vice versa

Three different types of loads



- Blue figure leaning to one side = inductive load
- Inductive load has shifted sinus wave (more specific: a delayed sinus)
- As discussed before

Conclusions

- Managing power system = highly complex
  - Power generated should at each moment exactly compensate for load
  - Frequency of the network (velocity of the bike) and voltage level (tension on the chain) should always remain steady