Department of Electronics & Electrical Engineering

Lecture 9

Analogy for Electrical Networks

The electrical system as a tandem bicycle

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

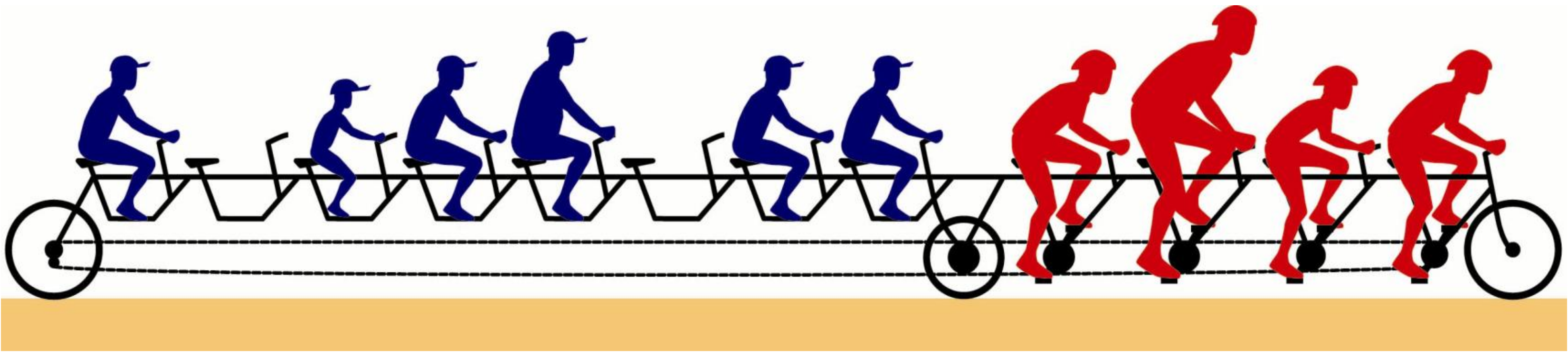
→ A good analogy to form a better idea of how things work

→ Comparison with a tandem bicycle

The electrical system as a tandem bicycle

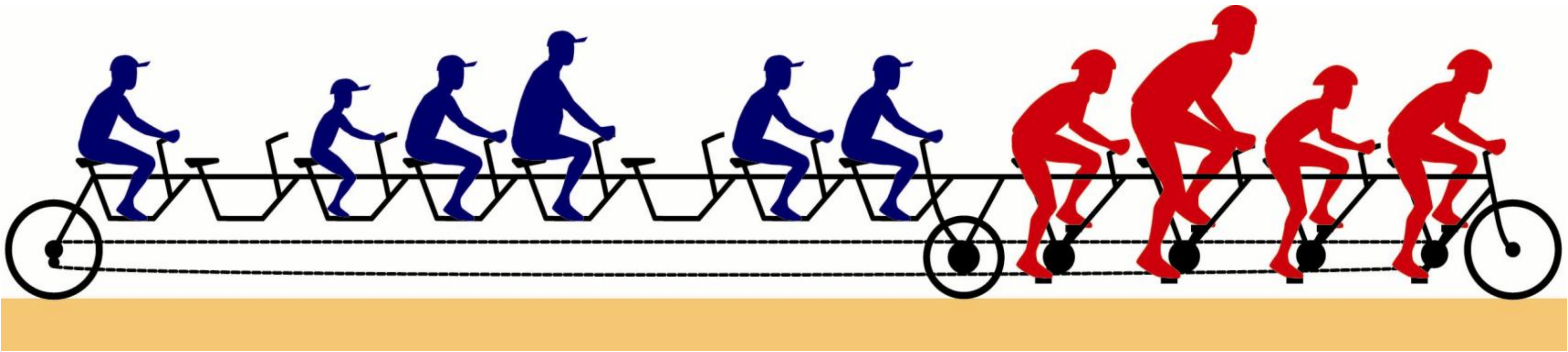
- No analogy is a 100% fit
  - Not all characteristics can be “translated”
  - Certain aspects of the analogy are not completely accurate
- Similarities are close enough
- Of great help in understanding the abstract electrical system

The basic representation of the system (1)



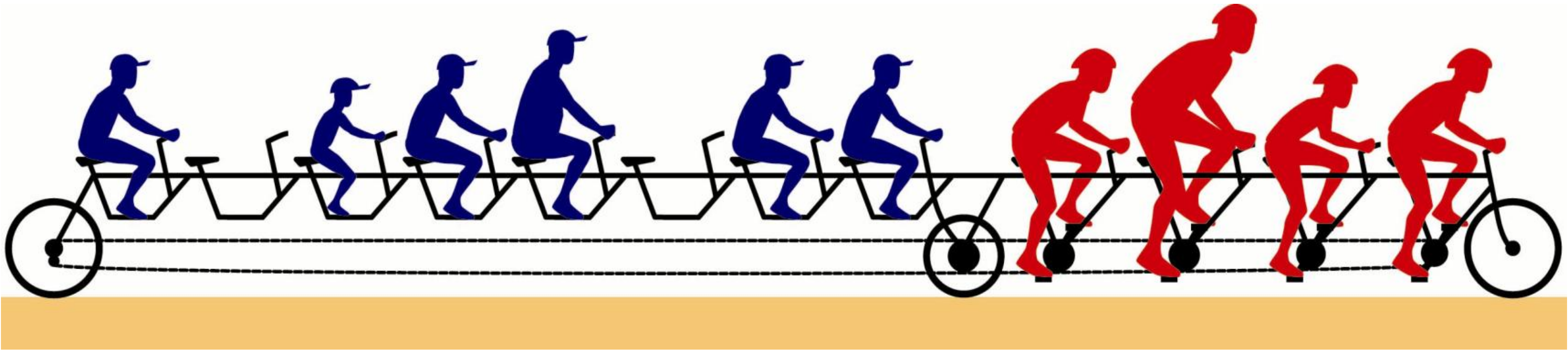
- Tandem bicycle moving at constant speed
- Goal: keep the blue figures moving
- Blue figures = load (industrial loads, private dwellings)
- Red figures = power stations (different sizes)

The basic representation of the system (2)



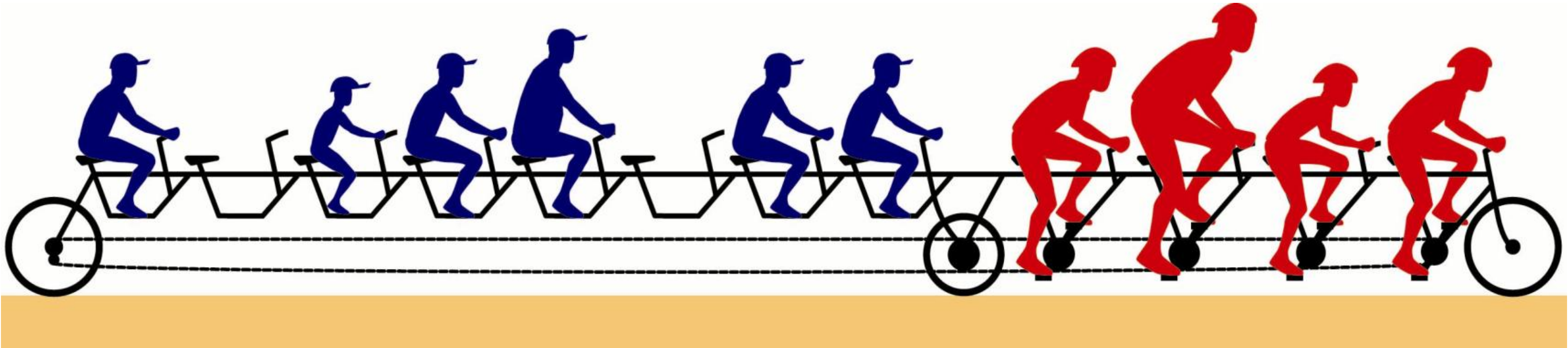
- Chain = electrical network
- Chain must turn at constant velocity (electrical network must have a constant frequency)
- Upper part chain must be under constant tension (an electrical connection should have constant voltage level)

The basic representation of the system (3)



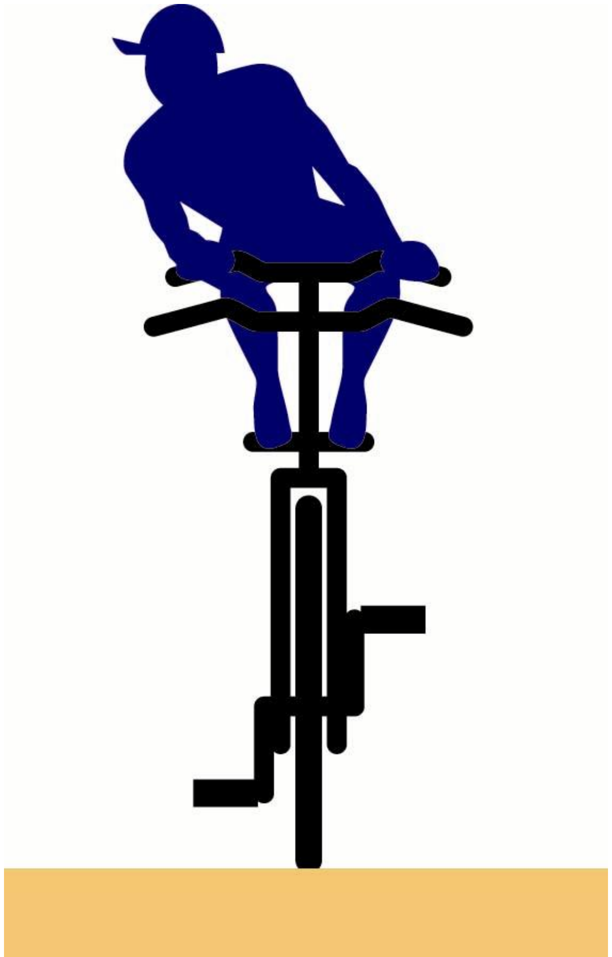
- **Lower part chain, without tension = neutral wire**
- **Gear transmitting energy to chain = transformer connecting power station and electrical network**

The basic representation of the system (4)



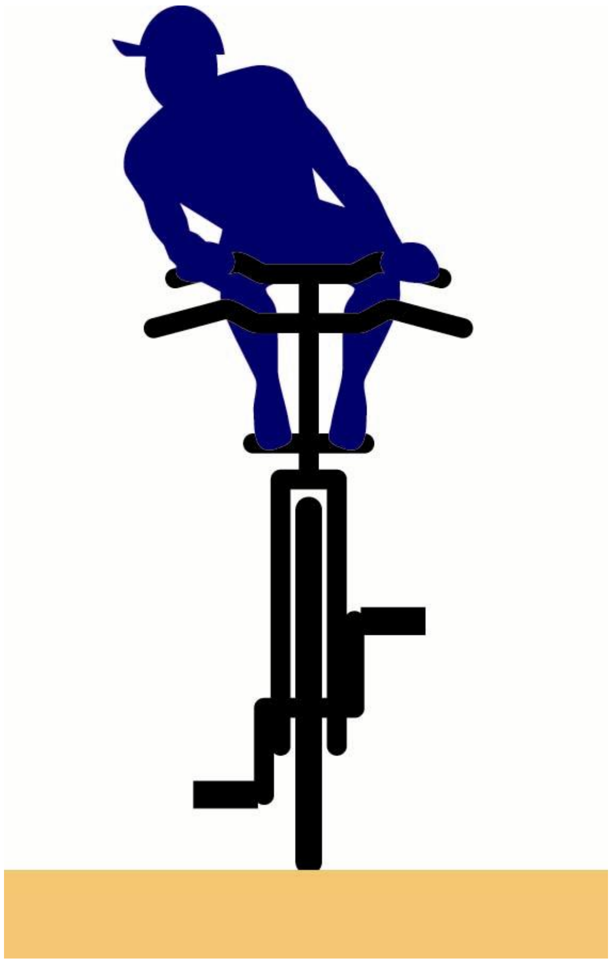
- Some red figures (power stations) don’t pedal at full power
- They’re able to apply extra force when
  - Another blue figure (load) jumps on the bike
  - One of the red figures (power stations) gets a cramp (= technical problems)

Inductive power and its compensation (1)



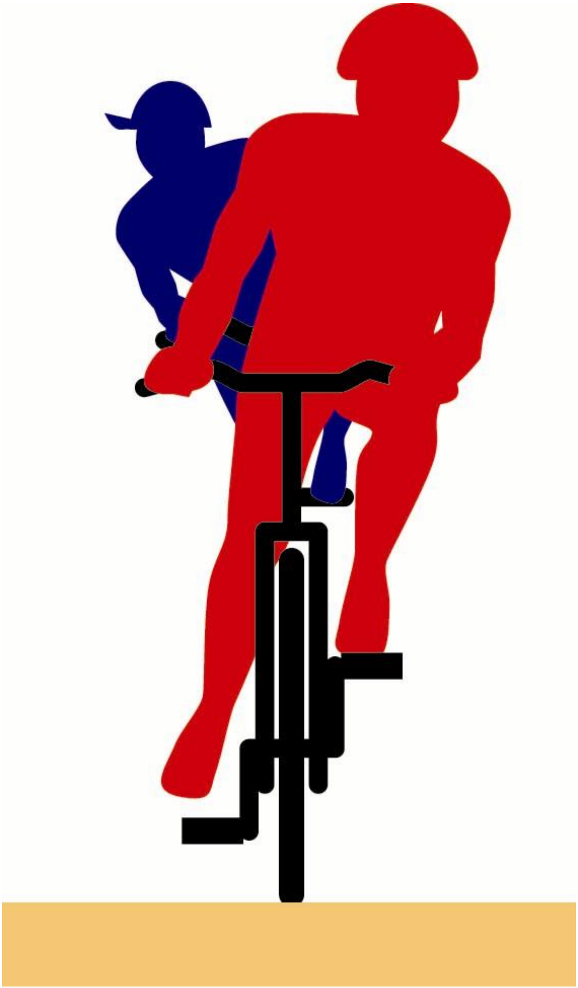
- Blue figure leaning to one side = inductive load
- Inductive load has shifted sinus wave (more specific: a delayed sinus)
- Origin: electrical motor induction coils, fluorescent lighting ballasts, certain types of electrical heating…

Inductive power and its compensation (2)



- **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**

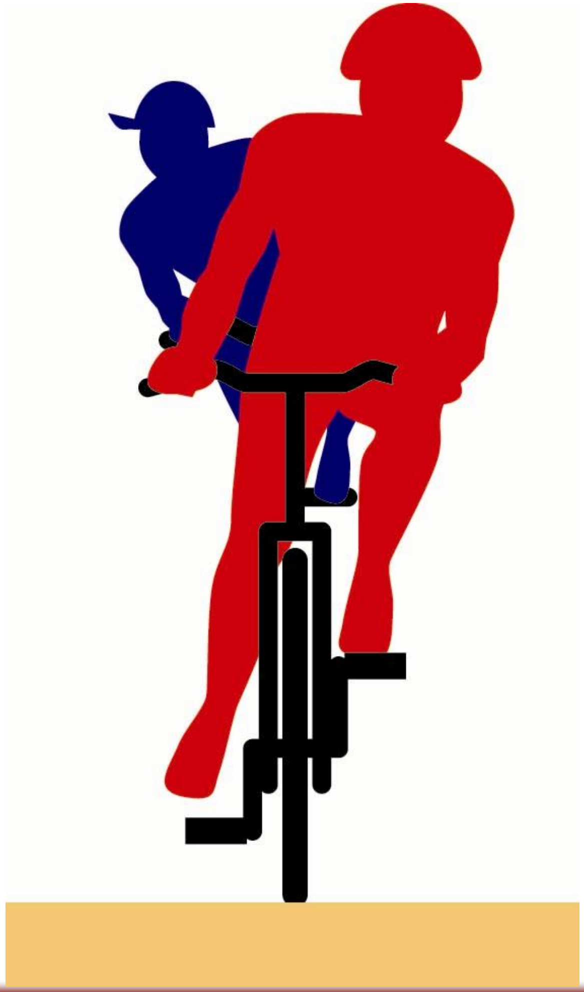
Inductive power and its compensation (3)



- **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 (4)



- **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 (5)

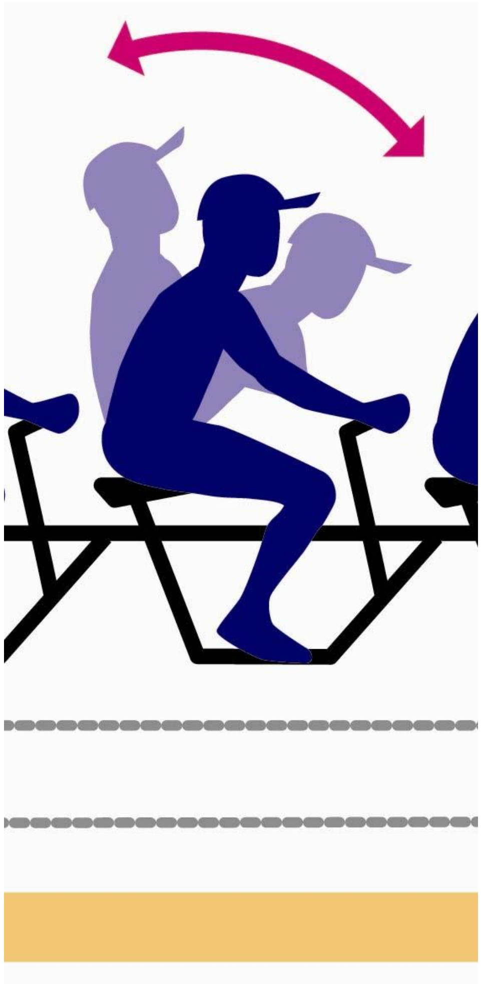
- **Better: compensate close to the source by a capacitive load = blue figure sitting close to inductive load but leaning to opposite side**
- **Capacitive load has sinus with lead time, compensating for delay in sinus of inductive load**

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 (2)



- 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 (1)

- 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 (2)

→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 (3)

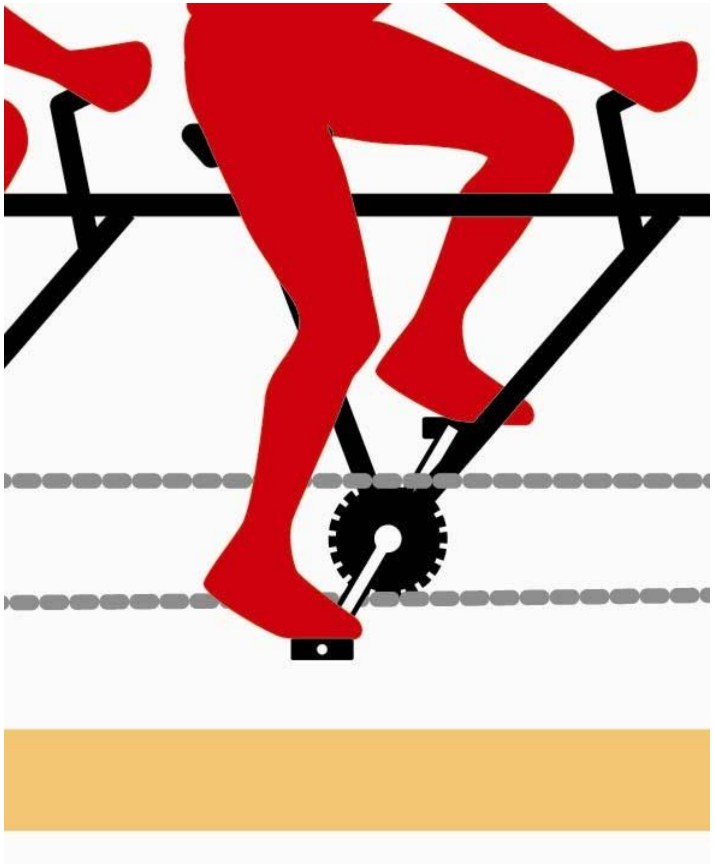
→ Risky to put foot on turning pedal again

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

Keeping constant voltage and frequency (4)

- **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**

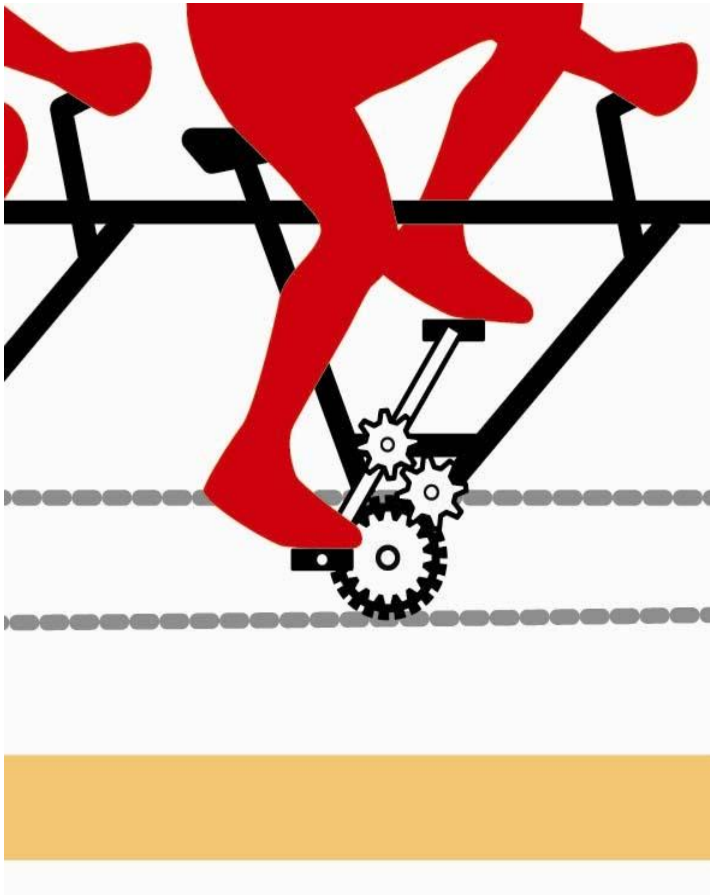
Three different types of power stations (1)



→ **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 (2)

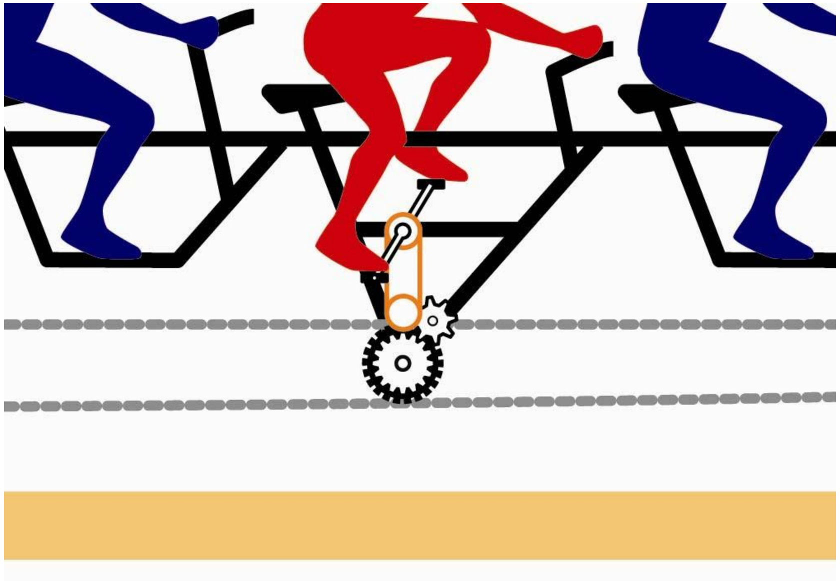


- Biker who can pedal slower
- Connected to chain by gear system

= 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 (3)

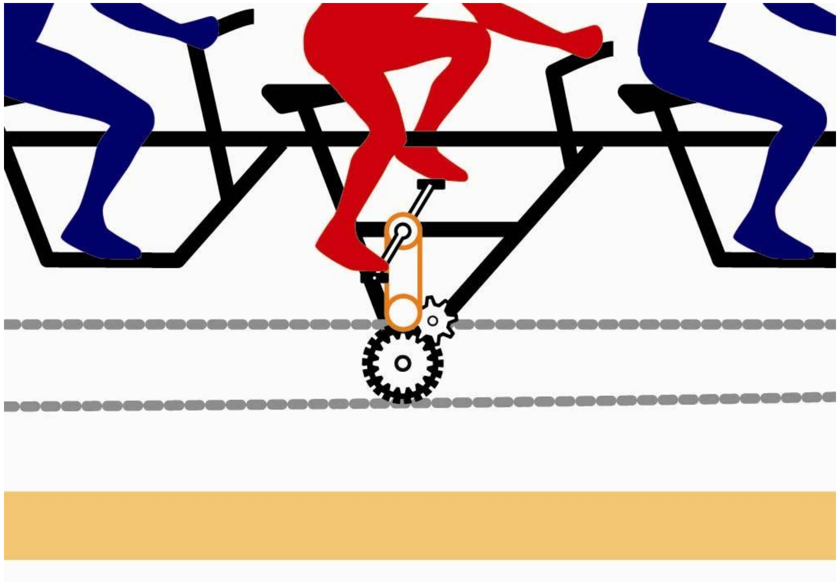


- Small red figure
- Pedalling only when the weather is nice
- Other bikers can’t rely on him

= 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 (4)

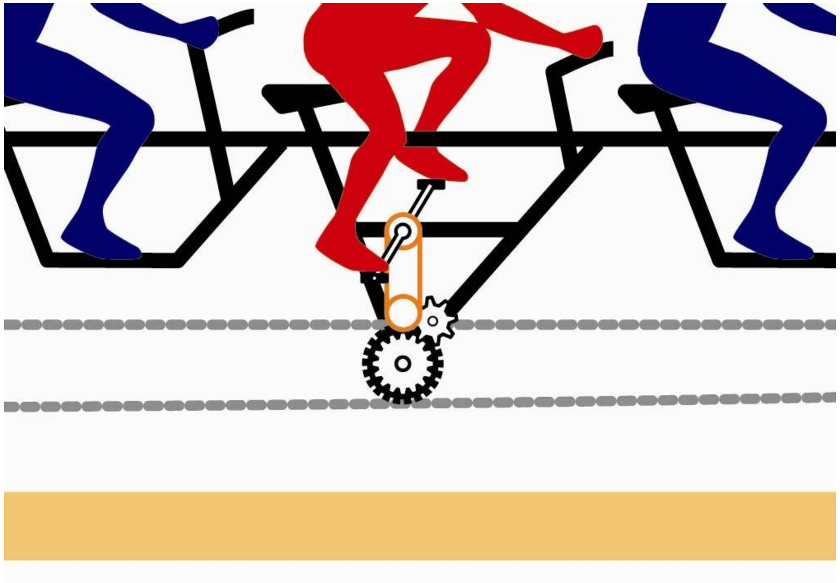


- **Connected by belt and gear system**

= 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 (5)



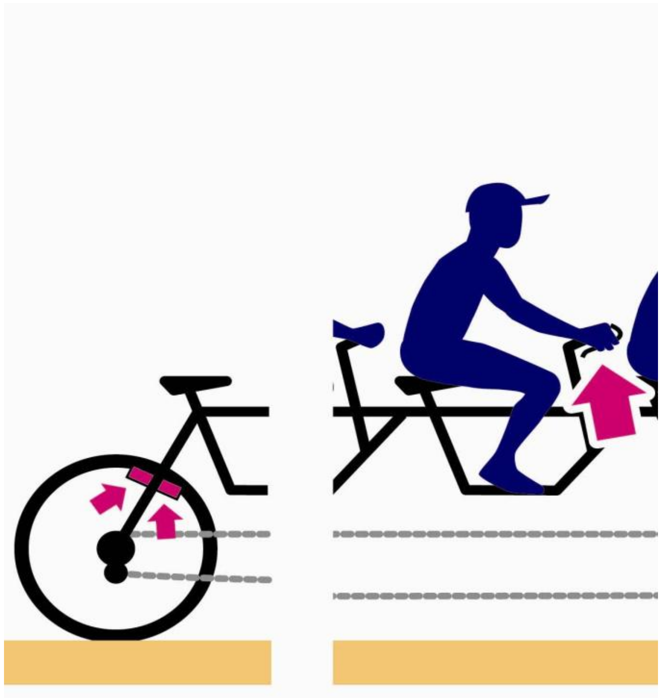
- **Why between blue riders?**

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 (1)



- **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**

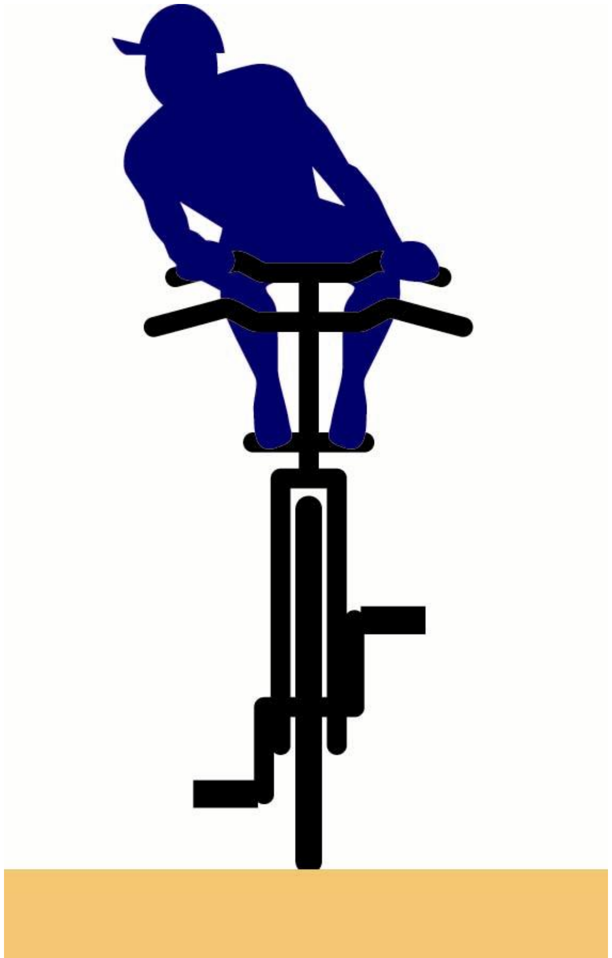
Three different types of loads (2)

- **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 (3)



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

Conclusion (1)

- 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