PSM Lab
EMI, Earthing & Corrosion

University of Cyprus
Department of Electrical and Computer Engineering

Introduction to Electrical Power Engineering

C. A. Charalambous, Associate Professor

September 2020

About the Lab

PSM Lab
EMI, Earthing & Corrosion

University of Cyprus
Department of Electrical and Computer Engineering

- The PSM Lab (est. 2013) operates under the auspices of the Department of ECE of the University of Cyprus.

- Research/Industrial Funding to date: 2 Million Euros

- Over 100 peer reviewed papers in top quality journal and international conferences

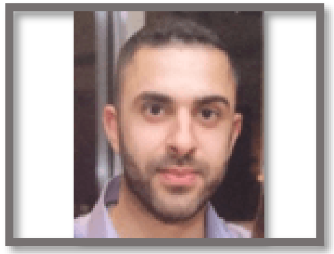
- Representation at the International Standardisation Committee, ISO/TC 67/SC 2/WG 24 for the development of the Technical Standard 21857 “Petroleum, Petrochemical and natural gas industries.

International Organization for Standardization

Lab Members & Research Interests

Senior Research Fellows

Dr. Antonis Lazari



Dr. Alexandros Nikolaidis

Leader

Prof. Charalambos A. Charalambous

Senior Research Fellows

Dr. Andreas Demetriou

Dr. Christos Melios

Other Lab members	
Mr Andreas Pallis	PhD candidate
Mr Fivos Therapontos	PhD candidate
Mr Nikos Kelliris	PhD candidate
Mr Michalis Yerou	Research Assistant
Mr Marios Grafanakis	Final Year UG student

- Electrical control and analysis of DC/AC interference from power system applications
- Engineering cost & benefit analysis and risk management
- Earthing/ lightning protection – railways, oil & gas pipelines, RES applications and LV systems
- Loss evaluation in distribution (MV/LV) power systems
- Insulation coordination in AC/DC micro-grids
- Power system plant and operation

Definition of Electrical Power

Definition:

- The rate at which the work is being done in an electrical circuit is called an electric power.
- The electric power is defined as the rate of the transferred of energy.
- The electric power is produced by the generator and can also be supplied by the electrical batteries.
- It can be carried over long distances
- It is converted into various other forms of energy like motion, heat energy.

$$Electrical\ Power = \frac{Work\ done\ in\ an\ electrical\ current}{time}$$

$$P = \frac{VIt}{t} = VI = IR^2 = \frac{V^2}{R}$$

$$V = 1\ volts\ and\ I = 1\ ampere$$

$$P = 1\ watt$$

Electrical Power vs Electrical Energy

Watts to kilowatt-hour calculation formula

The energy E in kilowatt-hour (kWh) is equal to the power P in watts (W), times the time period t in hours (hr) divided by 1000:

$$E_{(kWh)} = P_{(W)} \times t_{(hr)} / 1000$$

So

$$\text{kilowatt-hour} = \text{watt} \times \text{hour} / 1000$$

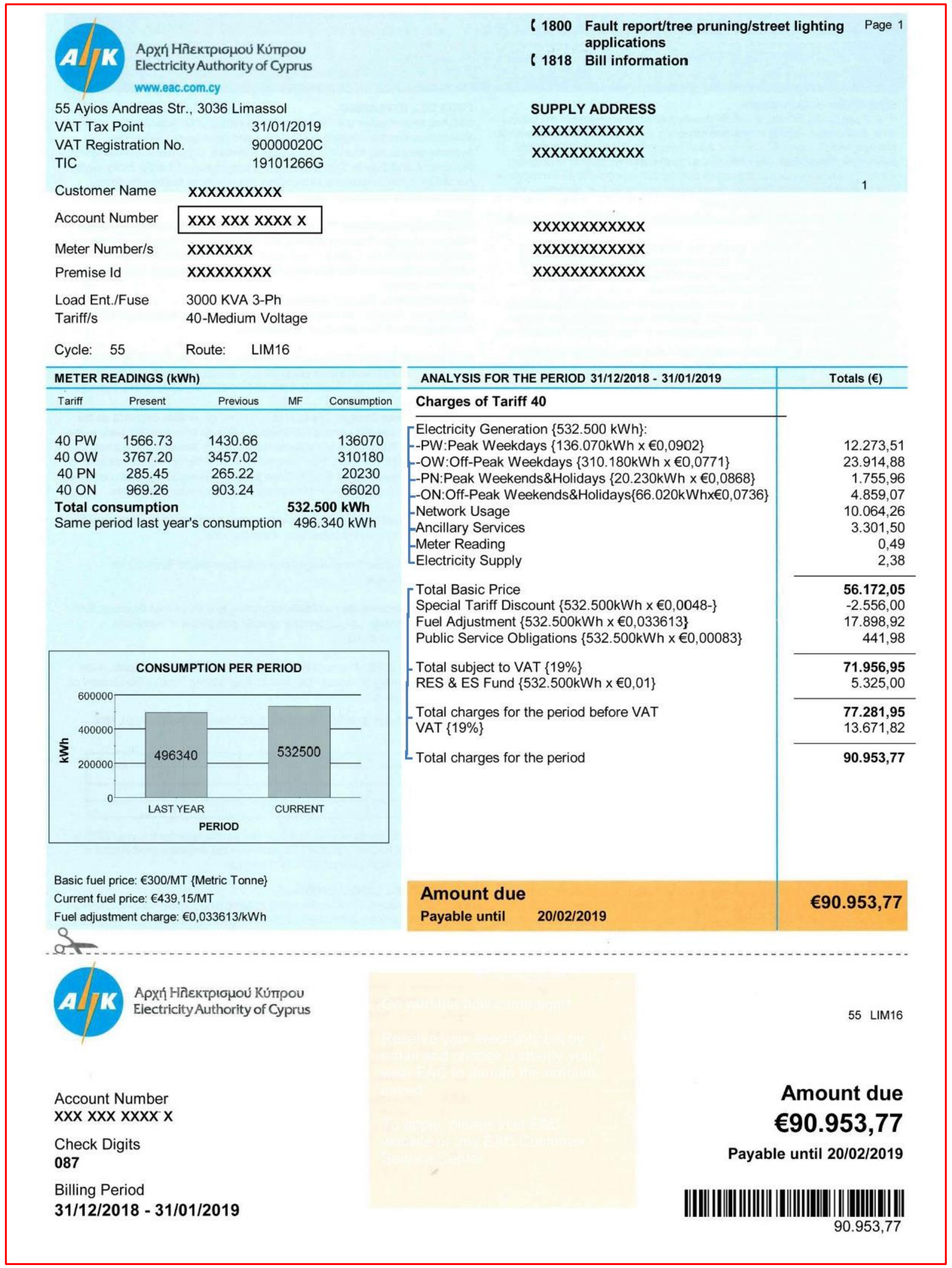
or

$$\text{kWh} = \text{W} \times \text{hr} / 1000$$

Example

What is the energy consumption in watt-hour when the power consumption is 5000 watts for time duration of 3 hours?

$$E = 5000\text{W} \times 3\text{h} / 1000 = 15\ \text{kWh}$$


Αρχή Ηλεκτρισμού Κύπρου
Electricity Authority of Cyprus
www.eac.com.cy

1800 Fault report/tree pruning/street lighting applications
1818 Bill information
Page 1

55 Ayios Andreas Str., 3036 Limassol
VAT Tax Point 31/01/2019
VAT Registration No. 90000020C
TIC 19101266G

SUPPLY ADDRESS
XXXXXXXXXXXX
XXXXXXXXXXXX

Customer Name XXXXXXXXXX
Account Number XXX XXX XXXX X
Meter Number/s XXXXXXX
Premise Id XXXXXXXXX
Load Ent./Fuse 3000 KVA 3-Ph
Tariff/s 40-Medium Voltage
Cycle: 55 Route: LIM16

XXXXXXXXXXXX
XXXXXXXXXXXX
XXXXXXXXXXXX

METER READINGS (kWh)

Tariff	Present	Previous	MF	Consumption
40 PW	1566.73	1430.66		136070
40 OW	3767.20	3457.02		310180
40 PN	285.45	265.22		20230
40 ON	969.26	903.24		66020

Total consumption 532.500 kWh
Same period last year's consumption 496.340 kWh

CONSUMPTION PER PERIOD
kWh: 600000, 400000, 200000, 0
LAST YEAR 496340; CURRENT 532500
PERIOD

ANALYSIS FOR THE PERIOD 31/12/2018 - 31/01/2019	Totals (€)
Charges of Tariff 40	
Electricity Generation {532.500 kWh}:	
-PW:Peak Weekdays {136.070kWh x €0,0902}	12.273,51
-OW:Off-Peak Weekdays {310.180kWh x €0,0771}	23.914,88
-PN:Peak Weekends&Holidays {20.230kWh x €0,0868}	1.755,96
-ON:Off-Peak Weekends&Holidays{66.020kWhx€0,0736}	4.859,07
Network Usage	10.064,26
Ancillary Services	3.301,50
Meter Reading	0,49
Electricity Supply	2,38
Total Basic Price	**56.172,05**
Special Tariff Discount {532.500kWh x €0,0048-}	-2.556,00
Fuel Adjustment {532.500kWh x €0,033613}	17.898,92
Public Service Obligations {532.500kWh x €0,00083}	441,98
Total subject to VAT {19%}	**71.956,95**
RES & ES Fund {532.500kWh x €0,01}	5.325,00
Total charges for the period before VAT	**77.281,95**
VAT {19%}	13.671,82
Total charges for the period	**90.953,77**

Basic fuel price: €300/MT {Metric Tonne}
Current fuel price: €439,15/MT
Fuel adjustment charge: €0,033613/kWh

Amount due €90.953,77
Payable until 20/02/2019

Αρχή Ηλεκτρισμού Κύπρου
Electricity Authority of Cyprus

55 LIM16

Account Number
XXX XXX XXXX X
Check Digits
087
Billing Period
31/12/2018 - 31/01/2019

Amount due
€90.953,77
Payable until 20/02/2019
90.953,77

Classification of Electrical Power

- The electric power is divided into two types:
  - the AC power
  - the DC power

- The classification of the electric power depends on the nature of the current or voltage (AC od DC)

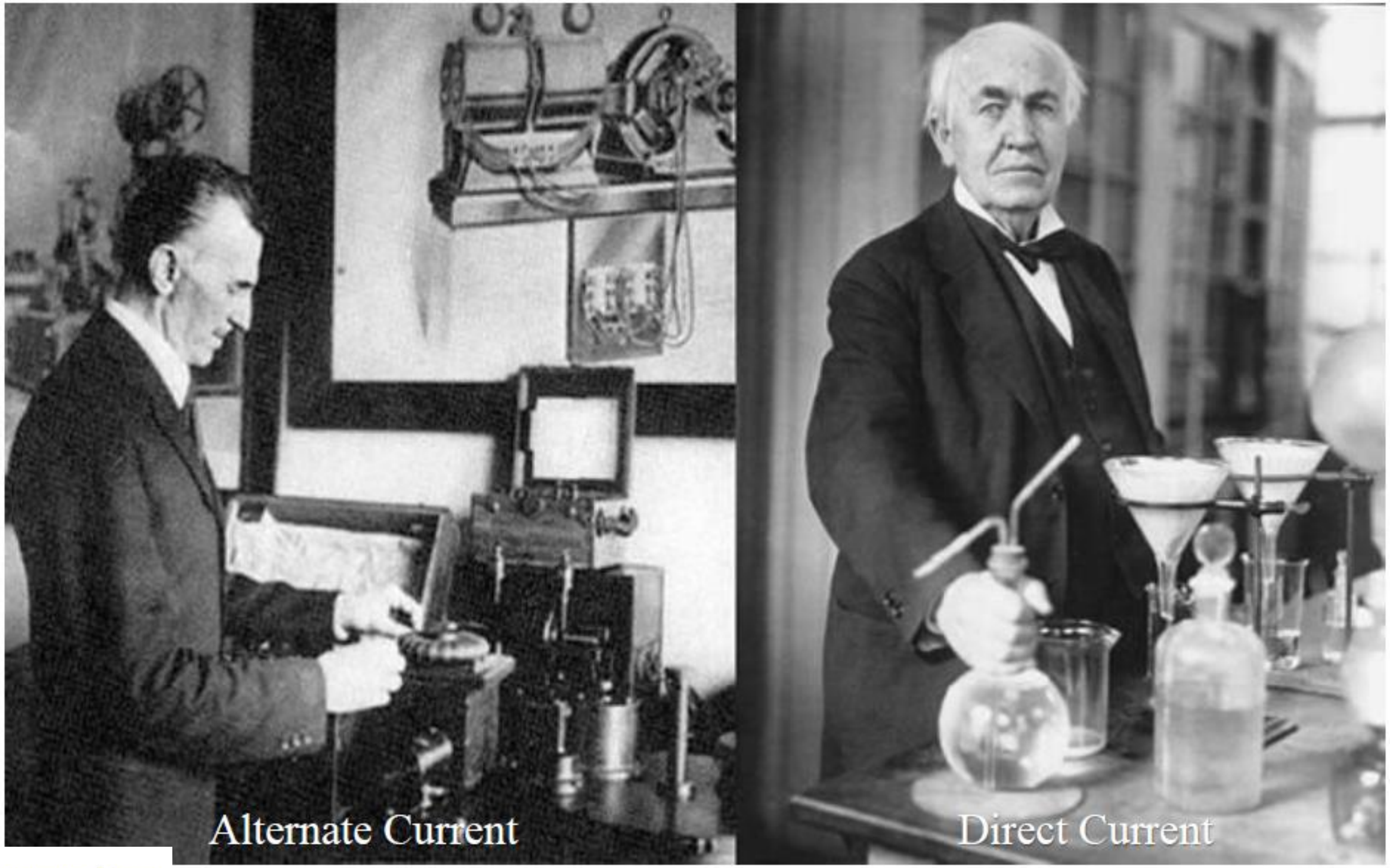
"AC"	Voltage Current	is	Voltage Current	*that changes*
"DC"	Voltage Current	is	Voltage Current	*that is steady*

[Recommended watch:](https://www.youtube.com/watch?v=vN9aR2wKv0U)

https://www.youtube.com/watch?v=vN9aR2wKv0U

Battle of Currents

- The **war of the currents**, sometimes called **battle of the currents**, was a series of events surrounding the introduction of competing electric power transmission systems in the late 1880s and early 1890s.



Nikola Tesla and Thomas Edison

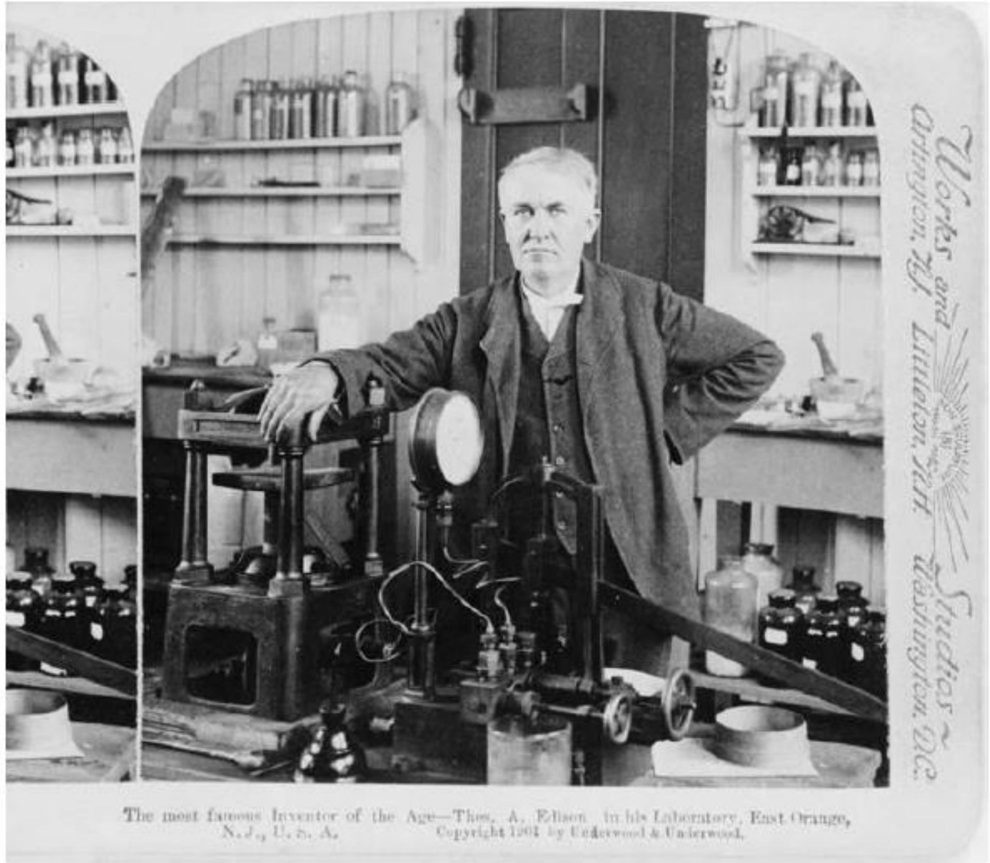
Battle of Currents or The Current War

The Current War is a 2017 American historical drama film inspired by the 19th-century competition between Thomas Edison and George Westinghouse over which electric power delivery system would be used in the United States (often referred to as the "war of the currents").

Brief History of Power Systems

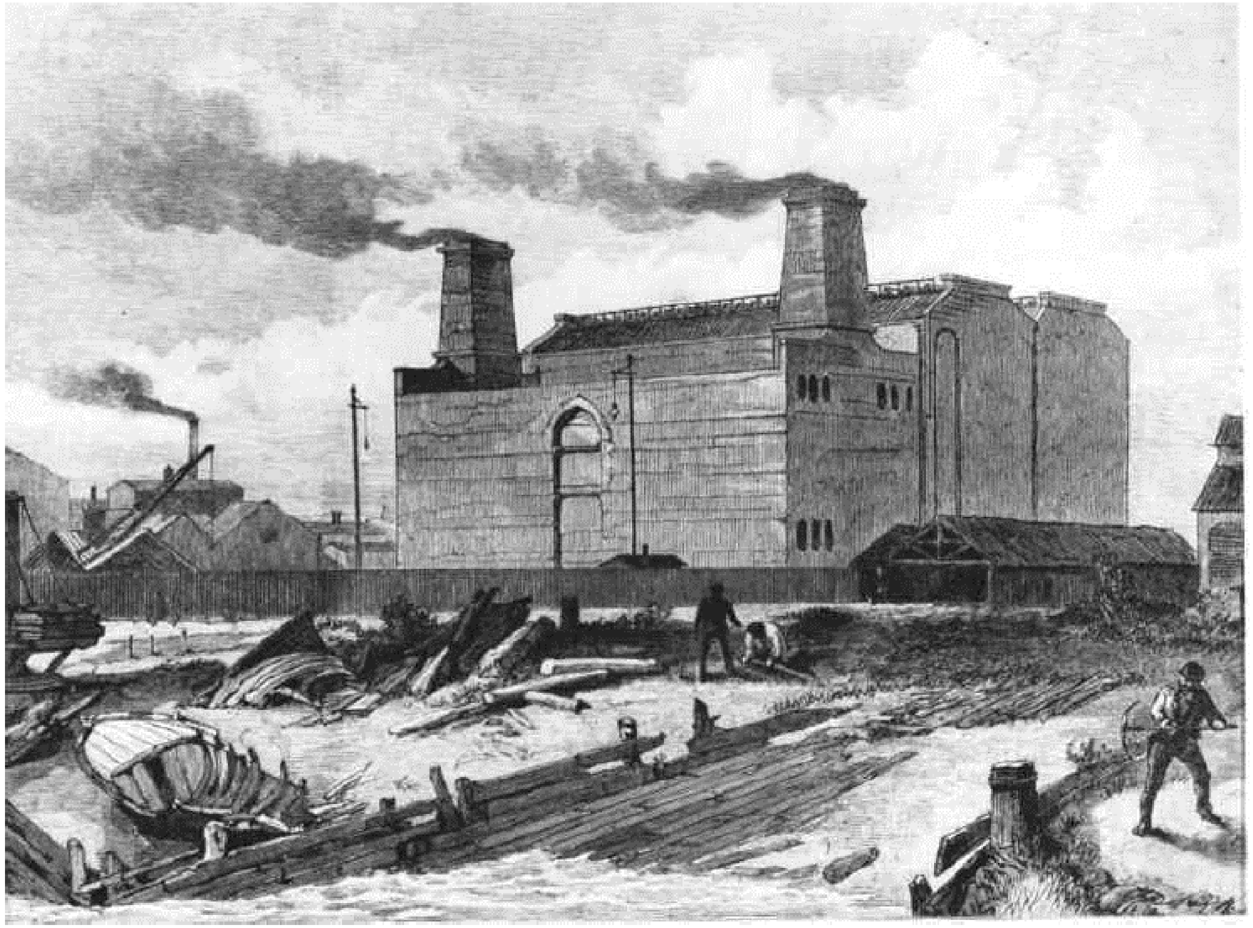
- **1882:** First central (DC) electricity generating station in the USA by Edison.
- Fed a load of 400 lamps, each of them consuming 83 W.

Pearl Street Power Station



Brief History of Power Systems

- **1887:** First major alternating current (AC) station in **Deptford** Great Britain by machines of 10000 h.p. and transmitted at 10 kV to consumers in London.



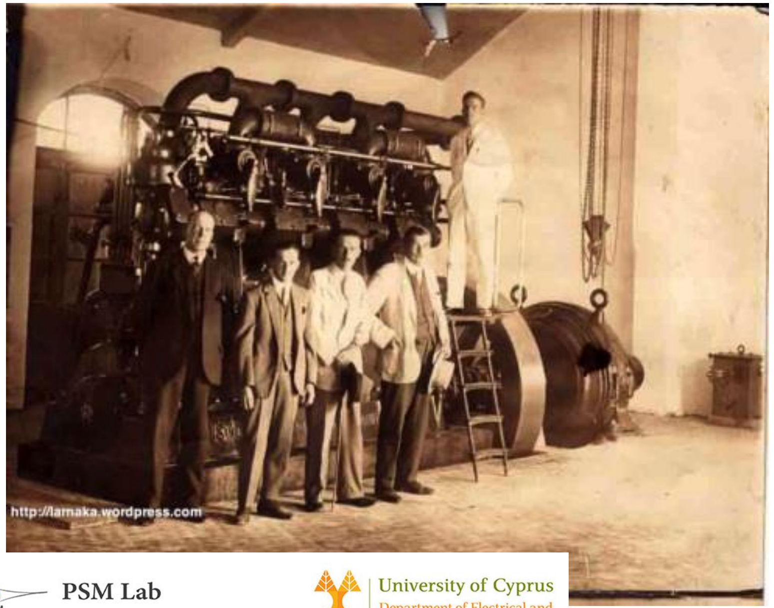
Deptford Power Station built 1887. It was the first major station to use the new-fangled high voltage AC. It was rebuilt a number of times before it was decommissioned in 1983 and demolished in 1992. See more at https://londonist.com/2012/03/the-history-of-londons-power-stations

Brief History of Power Systems: Cyprus

- Electricity was first introduced in 1903 with the installation by the then British colonial government of a power generator to serve the needs of the Commission in the capital, Nicosia. This was followed shortly afterwards by the installation of a second generator at the Lefkosia General Hospital.

- A limited number of Cypriots soon started to use electricity from 1912, when the first electricity company, which operated a power station with generators, was formed in Lemesos under the initiative of the Stamatiou brothers, George Yiannopoulos and other entrepreneurs from Lemesos. The company was called Ηλεκτροφωτιστική Εταιρεία Λεμεσού (The Limassol Electric Light Company).

You can read more on: https://www.eac.com.cy/EN/eac/organisation/Pages/History.aspx



Οι φωτογραφίες είναι από τα blog του Φοίβου Σταυρίδη και Σωκράτη Τ. Αντωνιάδη

https://perithorio.com/2018/10/04/%CE%BF-%CE%B7%CE%BB%CE%B5%CE%BA%CF%84%CF%81%CE%B9%CF%83%CE%BC%CF%8C%CF%82-%CF%83%CF%84%CE%B7%CE%BD-%CE%BA%CF%8D%CF%80%CF%81%CE%BF-%CE%BC%CE%B9%CE%BA%CF%81%CF%8C-%CE%B9%CF%83%CF%84%CE%BF%CF%81%CE%B9/

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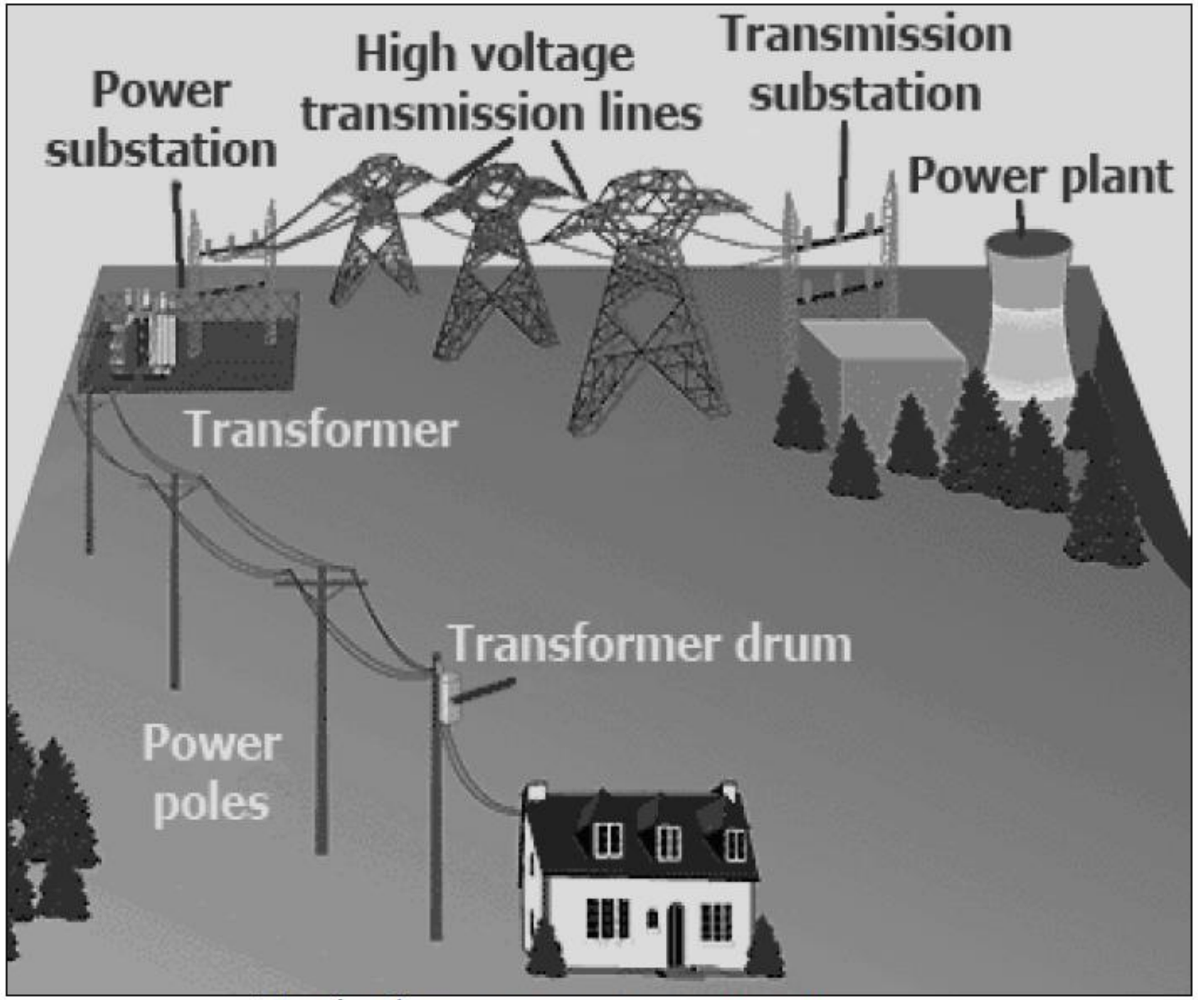
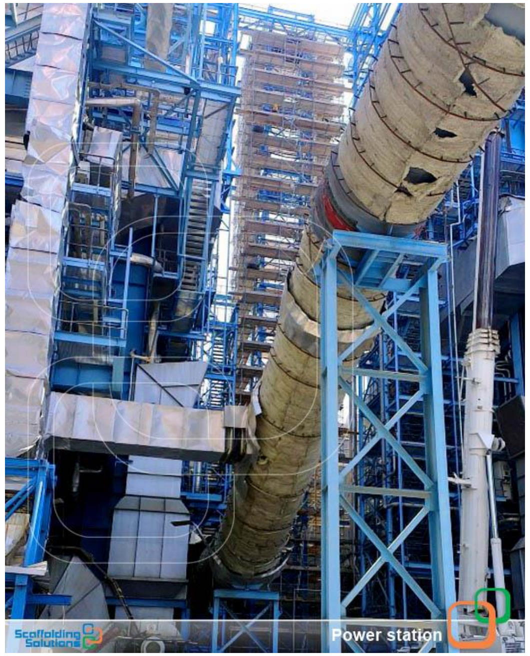
Electric Power Systems: What is their purpose?

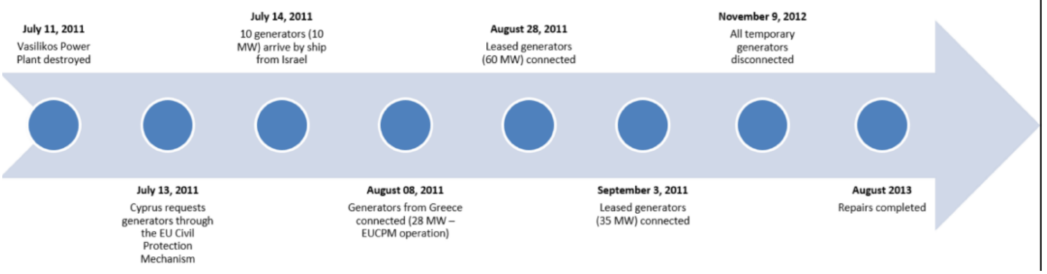
- **Transfer electric energy from point A to point B:**
  - Do it safely (don't kill anyone)
  - Do it reliably (continuous supply, no interruptions)
  - Do it environmentally friendly
  - Do it at a low cost and accessible to all



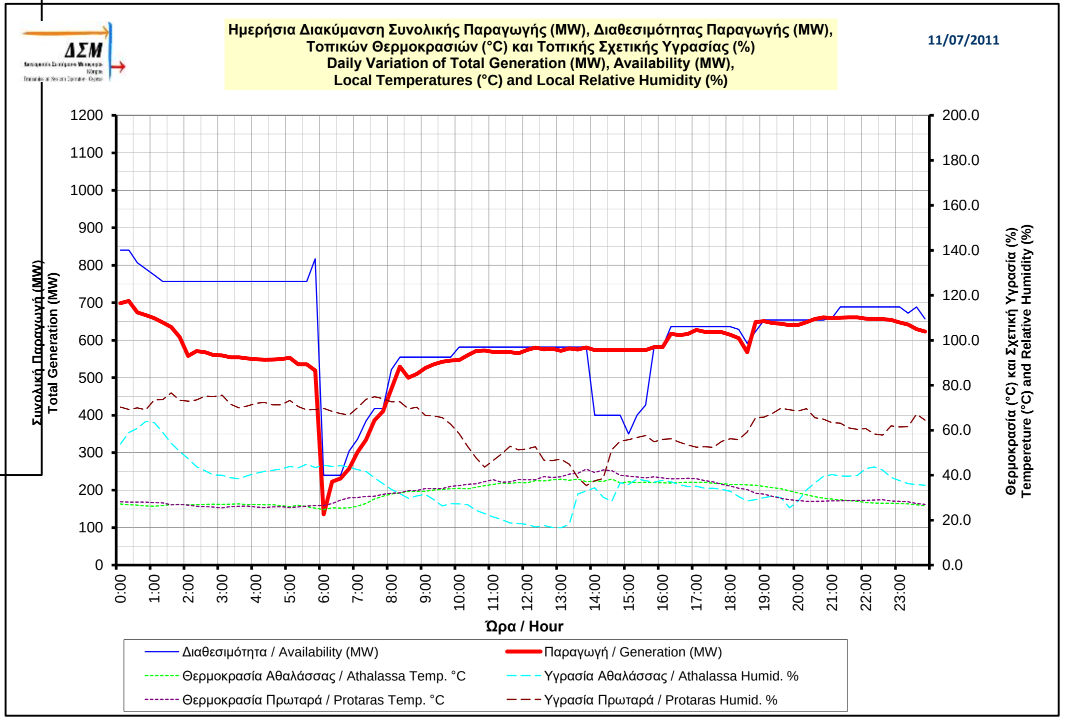
Typical power system structure.


Scaffolding Solutions
Power station

Electric Power Systems: How bad can an outage be?



Karagiannis, et al. "Power grid recovery after natural hazard impact", tech. rep., 2017



- The Cyprus outage of 2011 affected all of the population on the island, leading to reduced supply and scheduled outages over a prolonged period of time
- Triggered by an explosion at Evangelos Florakis Naval Base that destroyed the Vasilikos Power Plant
- Almost 60% of the island's power generating capacity was destroyed
- Estimated economic losses from power interruption[1] around 840 million euros per year

[1] T. Zachariadis, A. Poullikkas, The costs of power outages: A case study from Cyprus, Energy Policy, 2012

ΒΛΑΒΕΣ

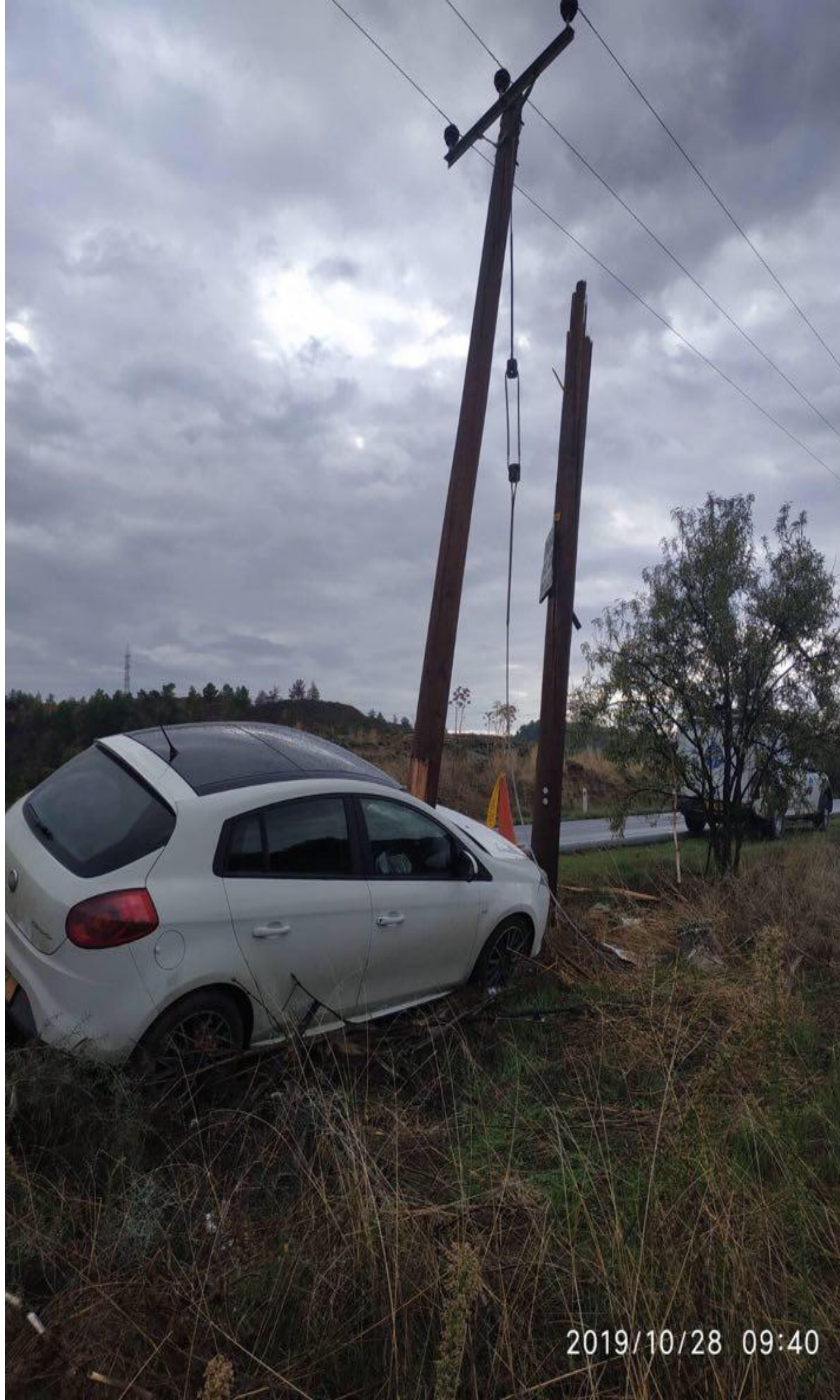
- ΑΝΕΜΟΣΤΡΟΒΥΛΟΣ 2020
  ΑΣΤΡΟΜΕΡΙΤΗΣ – ΝΙΚΗΤΑΡΙ

Πανεπιστήμιο Κύπρου

Αρχή Ηλεκτρισμού Κύπρου

ΒΛΑΒΕΣ

- ΑΝΕΜΟΣΤΡΟΒΥΛΟΣ 2020
  ΑΣΤΡΟΜΕΡΙΤΗΣ – ΝΙΚΗΤΑΡΙ

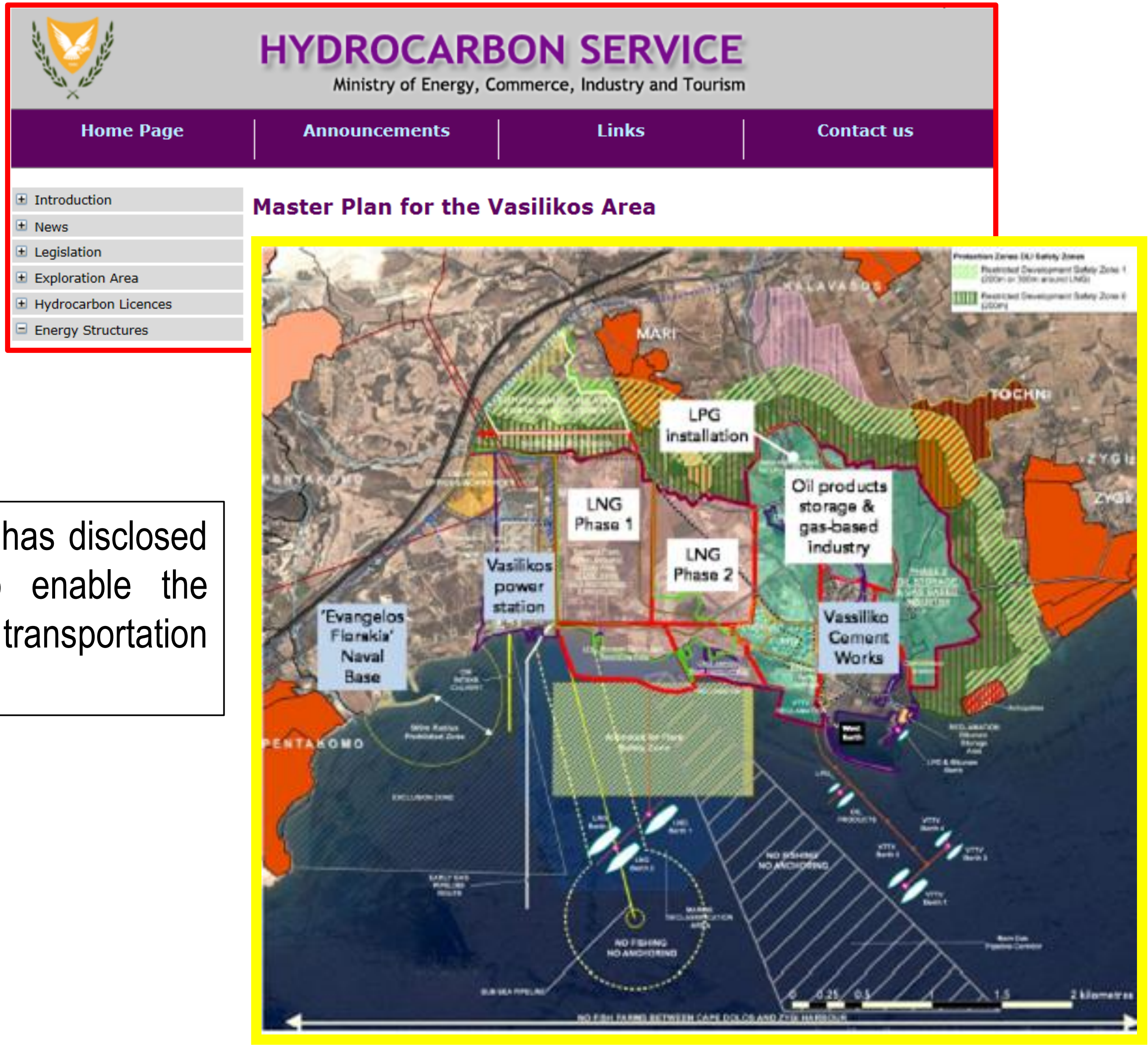


ΒΛΑΒΕΣ

- ΑΝΘΡΩΠΙΝΟΣ ΠΑΡΑΓΟΝΤΑΣ

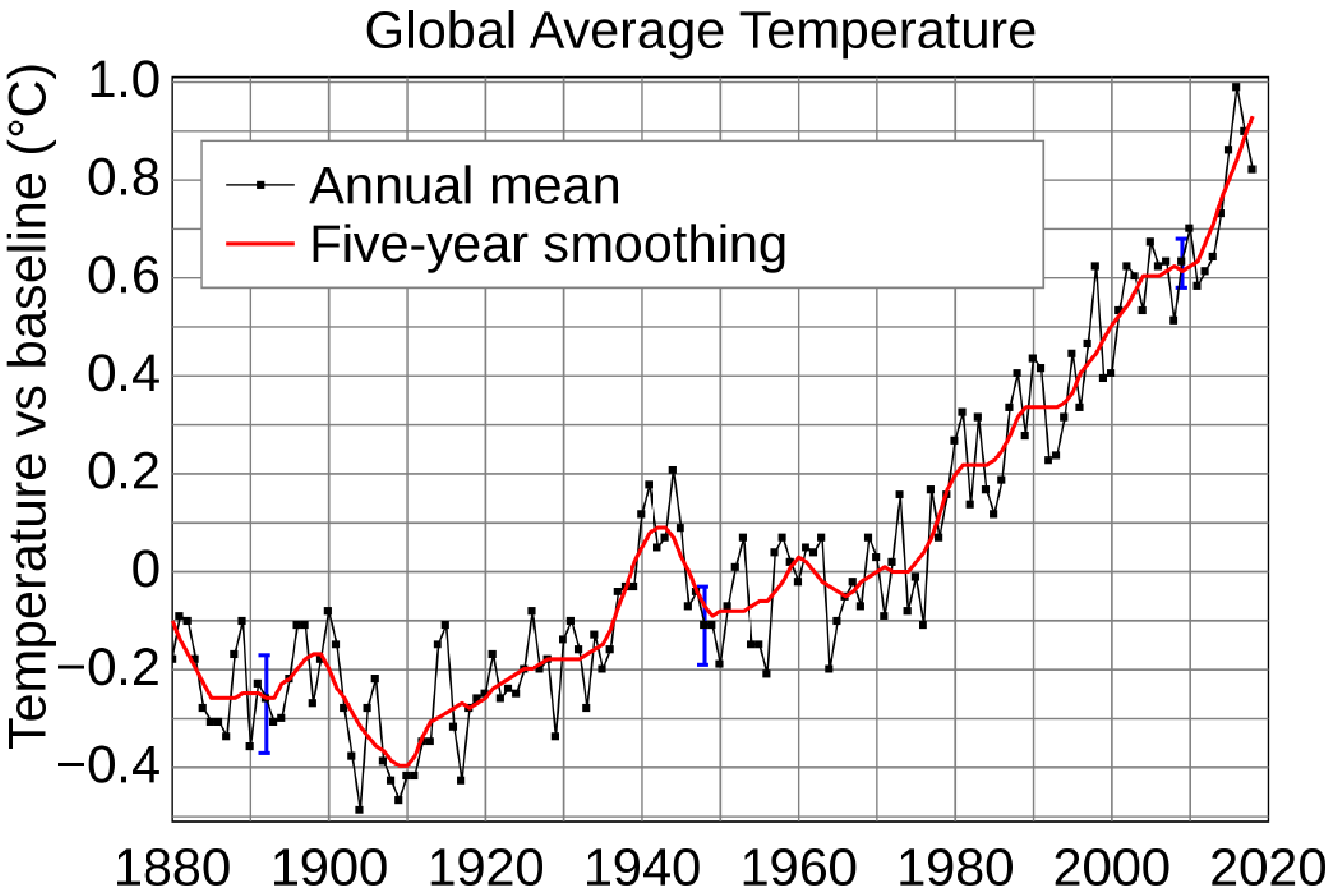
Concentrating Critical Assets in Vasilikos area

- **Fact (?) :** Cyprus currently ramps up its own energy exploration with plans for **natural gas pipelines** and **storage terminals**, to facilitate the transportation of gas supplies within Cyprus and abroad.



- The Hydrocarbon service of the Ministry of Energy has disclosed its master plan for the Vassilikos Area – to enable the **development of critical infrastructures** for the transportation and storage of gas and oil.

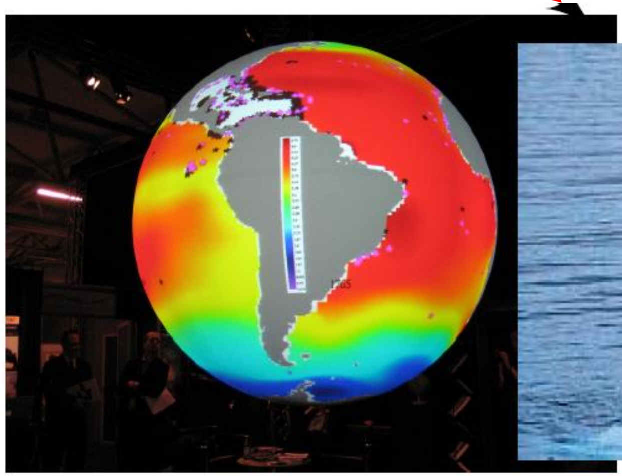
Electric Power Systems: Environmental aspects



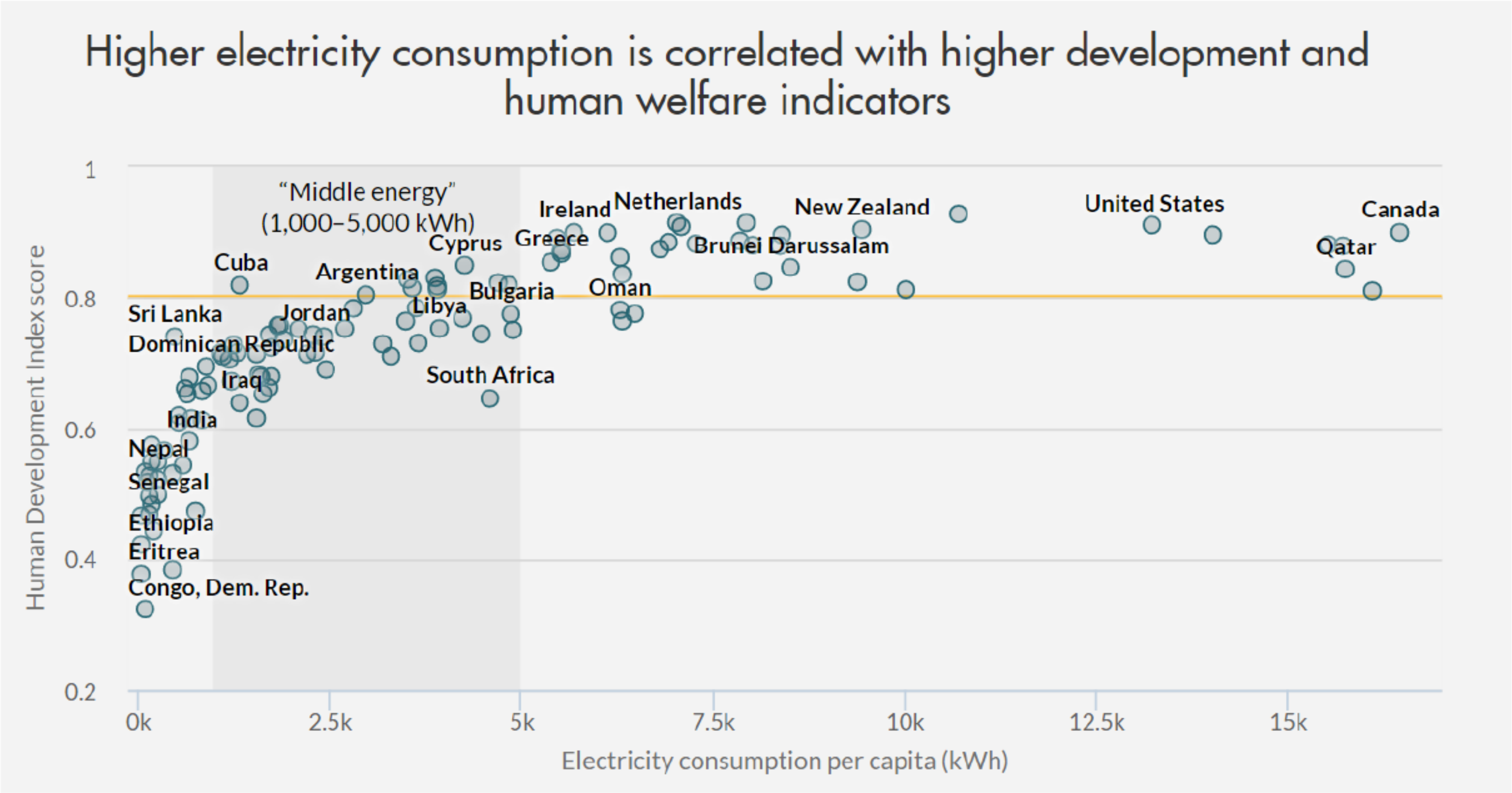
https://tsoc.org.cy/archive-total-daily-system-generation-on-the-transmission-system/?startdt=yesterday&enddt=yesterday

Problems with the use of Fossil Fuels

- Energy Generation from fossil fuels -→ contributes to greenhouse gas emissions and climate change
- Fossil fuels are finite

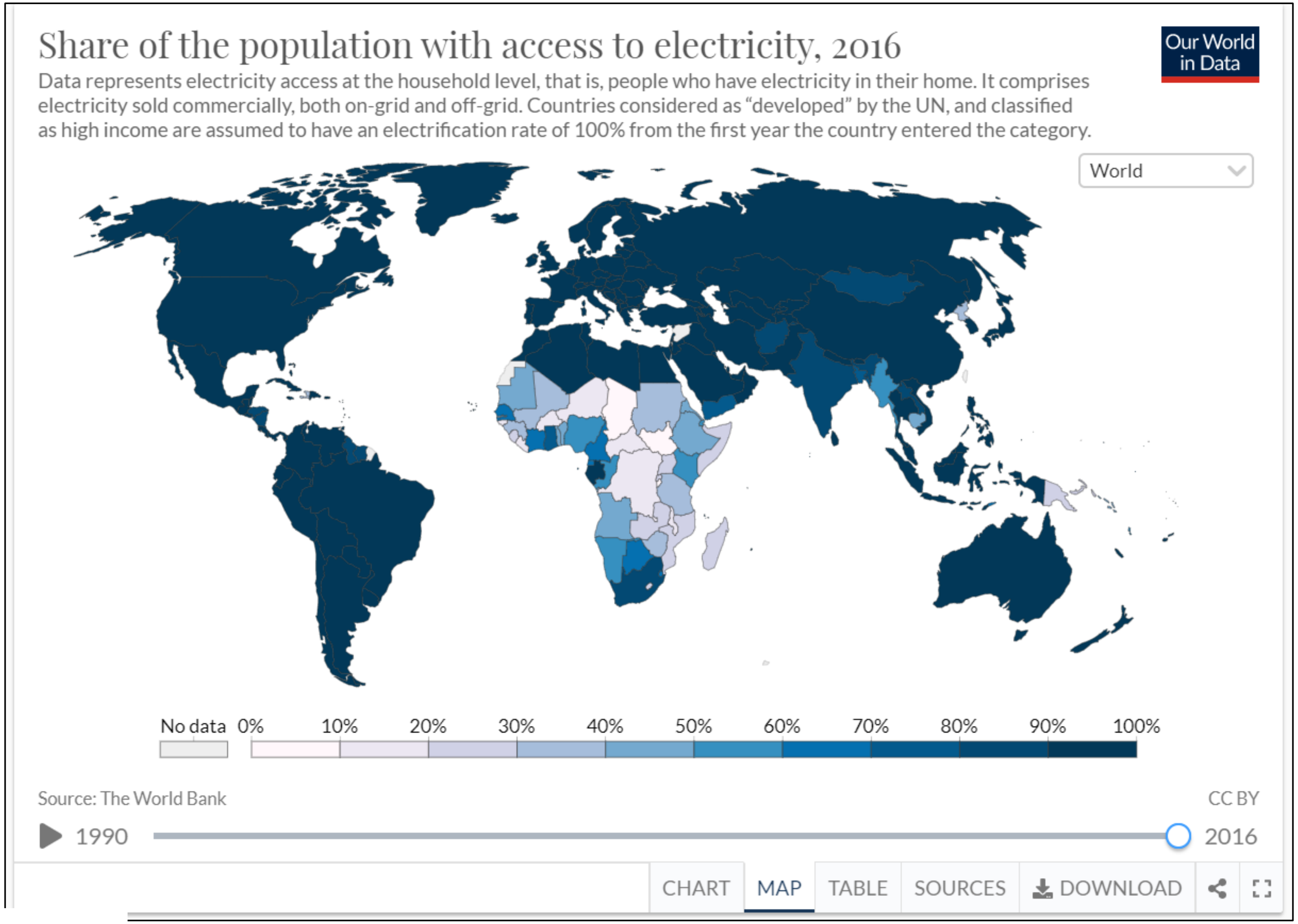


Cost of Energy and Development



Source: UNDP Human Development Index (2013); World Bank, World Development Index (2013)

Share of Population with access to Electricity



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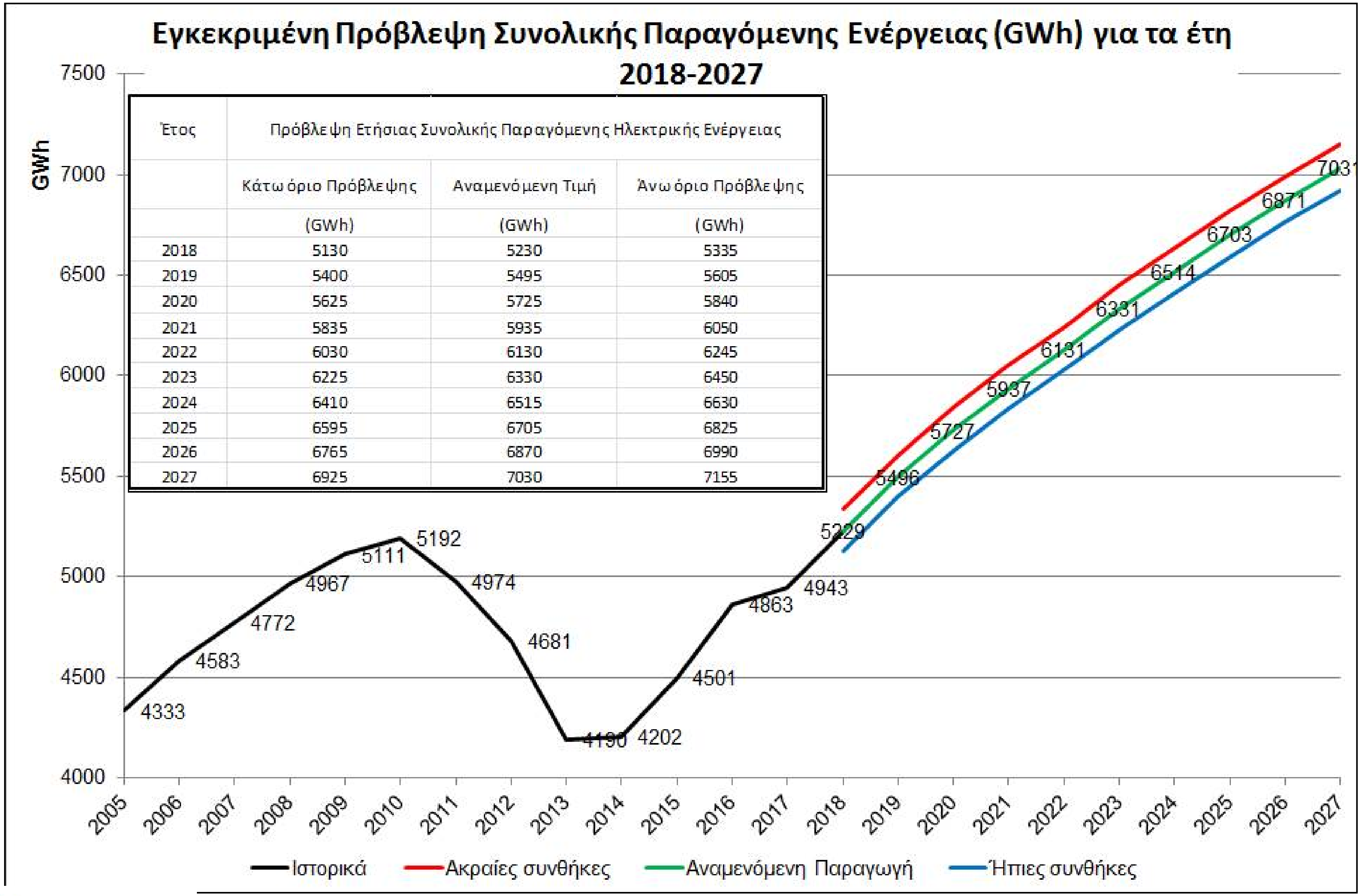
https://ourworldindata.org/energy-access

Forecast on Electricity Usage: the case of Cyprus



Έτος	Πρόβλεψη Ετήσιας Συνολικής Παραγόμενης Ηλεκτρικής Ενέργειας		
	Κάτω όριο Πρόβλεψης (GWh)	Αναμενόμενη Τιμή (GWh)	Άνω όριο Πρόβλεψης (GWh)
2018	5130	5230	5335
2019	5400	5495	5605
2020	5625	5725	5840
2021	5835	5935	6050
2022	6030	6130	6245
2023	6225	6330	6450
2024	6410	6515	6630
2025	6595	6705	6825
2026	6765	6870	6990
2027	6925	7030	7155

Why the design of Electric Power Systems is a complex issue?

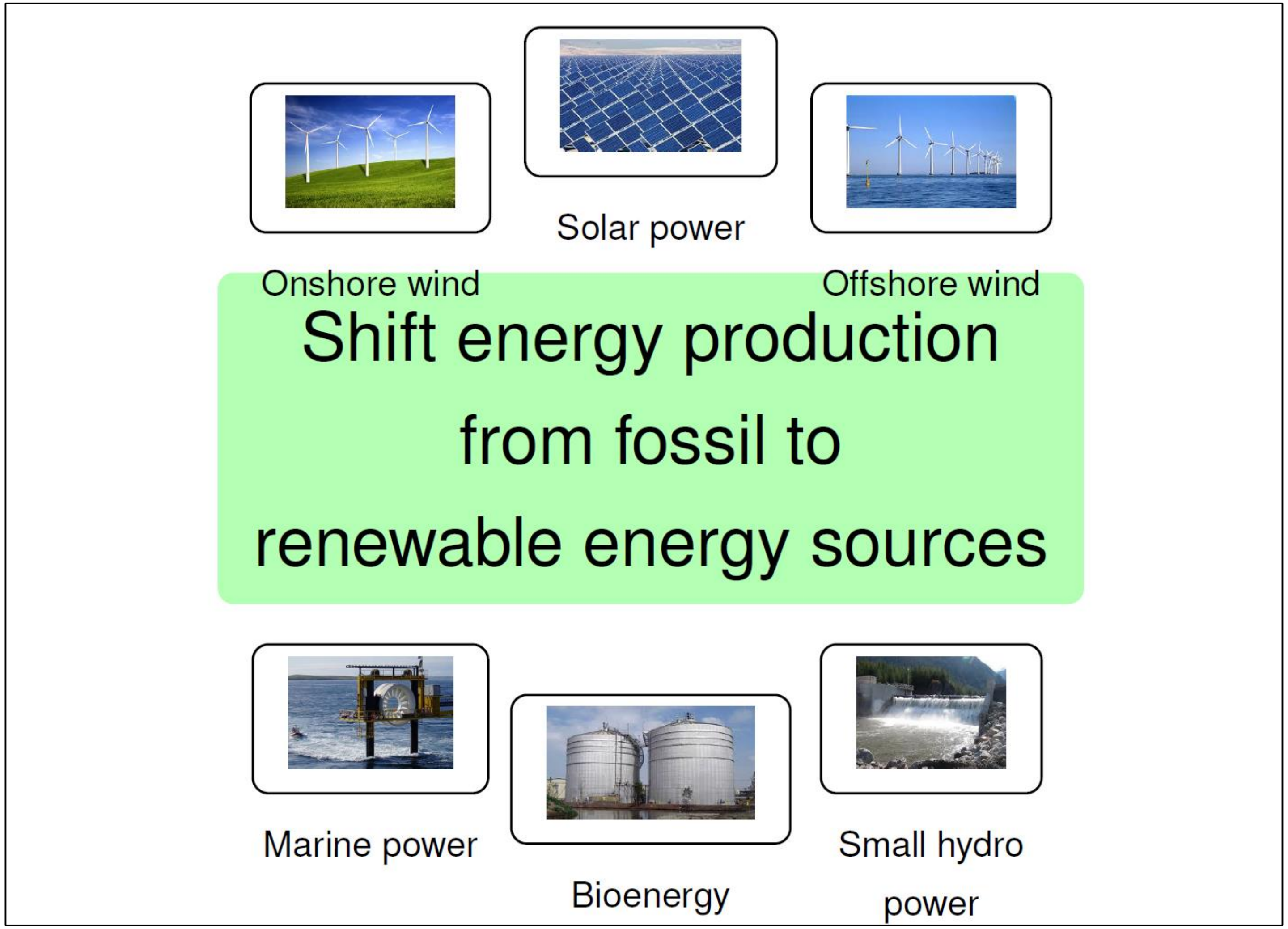
- **Transfer electric energy from point A to point B:**
  - Do it safely (don't kill anyone)
  - Do it reliably (continuous supply, no interruptions)
  - Do it environmentally friendly
  - Do it at a low cost and accessible to all

Why is it hard to do these?

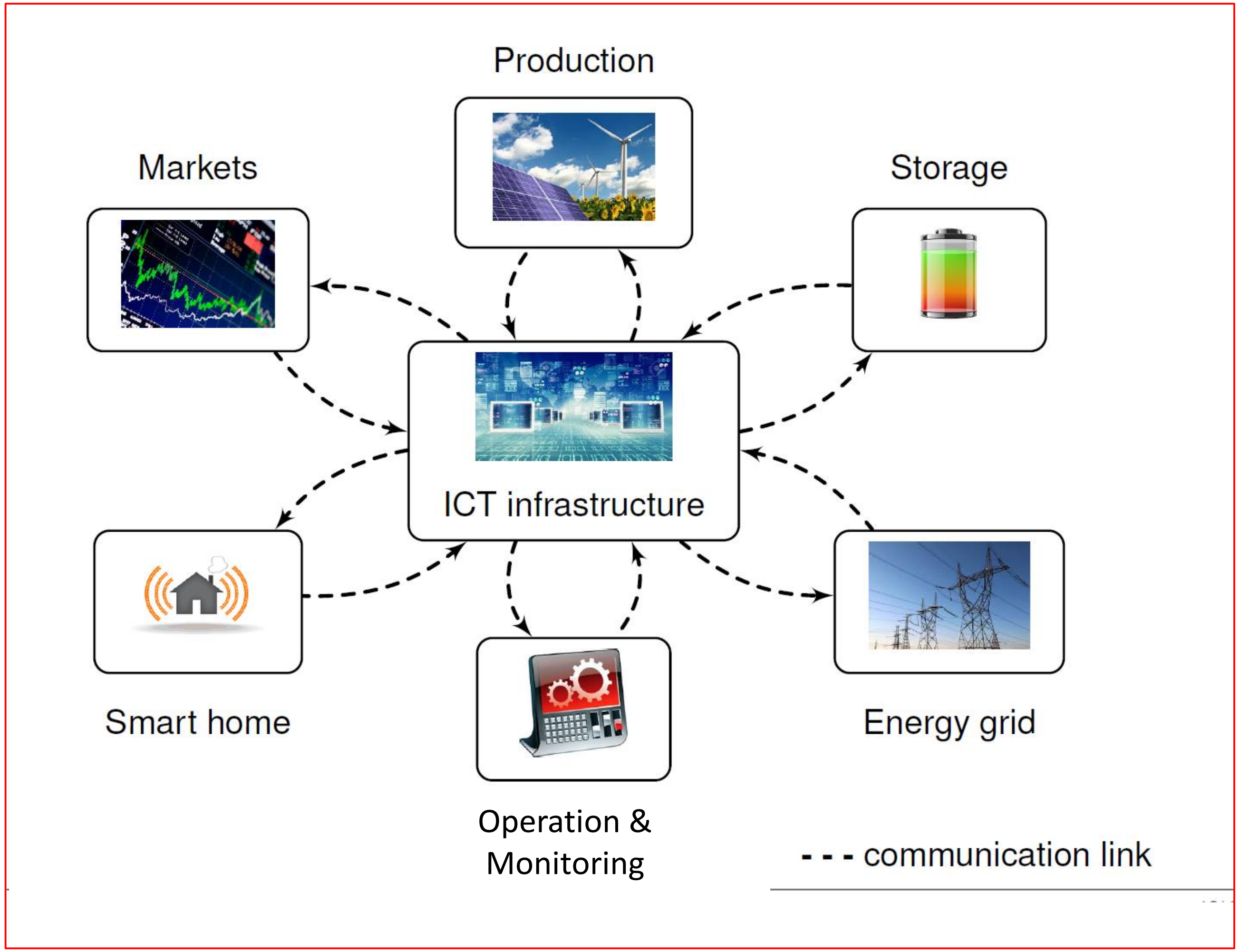
- World's largest and most complex engineered systems
- Modern industrialized societies heavily rely on use and steady supply of electric energy
- Power systems are expected to be very reliable
- Even a single failure can have catastrophic consequences for society!
- In addition: power systems continuously subjected to large variety of disturbances and contingencies (lighting, hurricanes, human errors,. . .)

→ Rather complex and sophisticated industrial processes behind electric energy supply!

More challenges are introduced by the Integration of Renewable Energy Systems (RES)



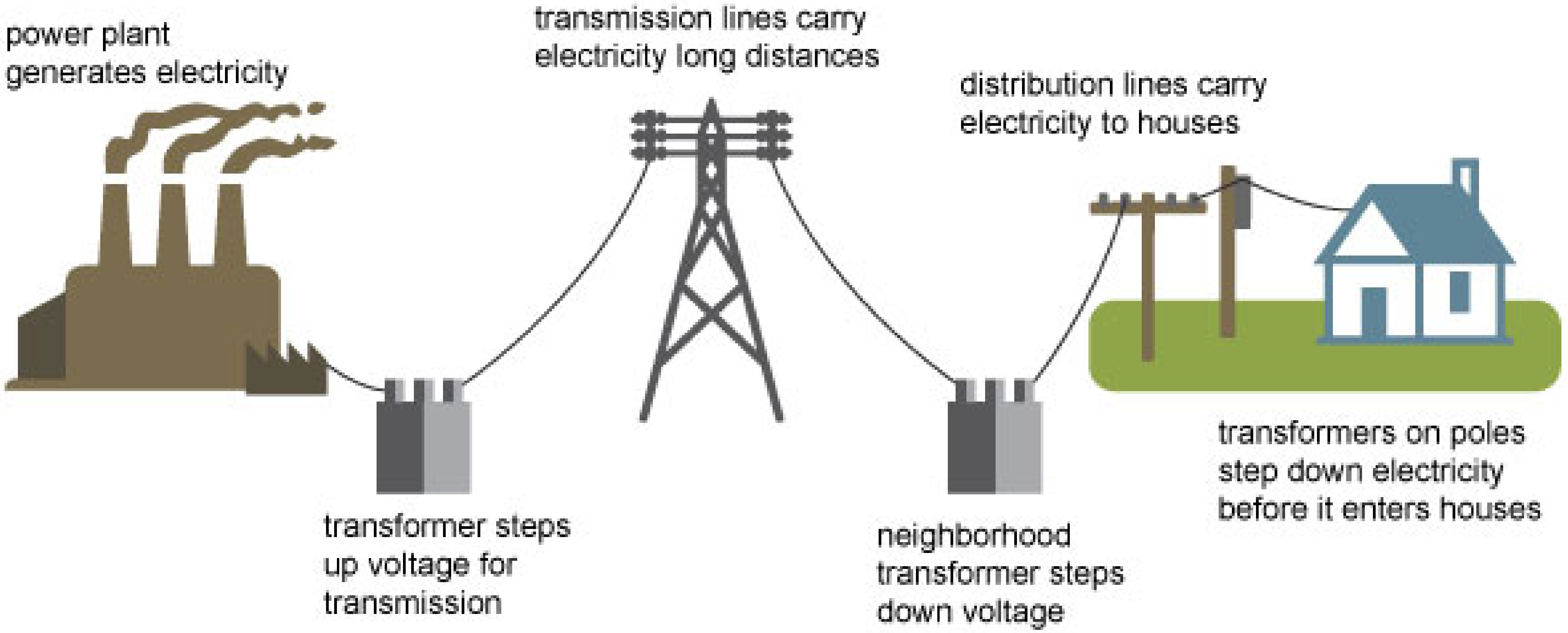
Current and Future Power Systems: More controllable & observable



- Key ingredients: ICT, renewables, flexible operation & consumption
- Many challenging open questions
- Large investments (EU-wide 500 billion euros by around 2020)

⇒ Plenty of exciting & interdisciplinary opportunities

Generation, Transmission and Distribution of Electricity: The basics



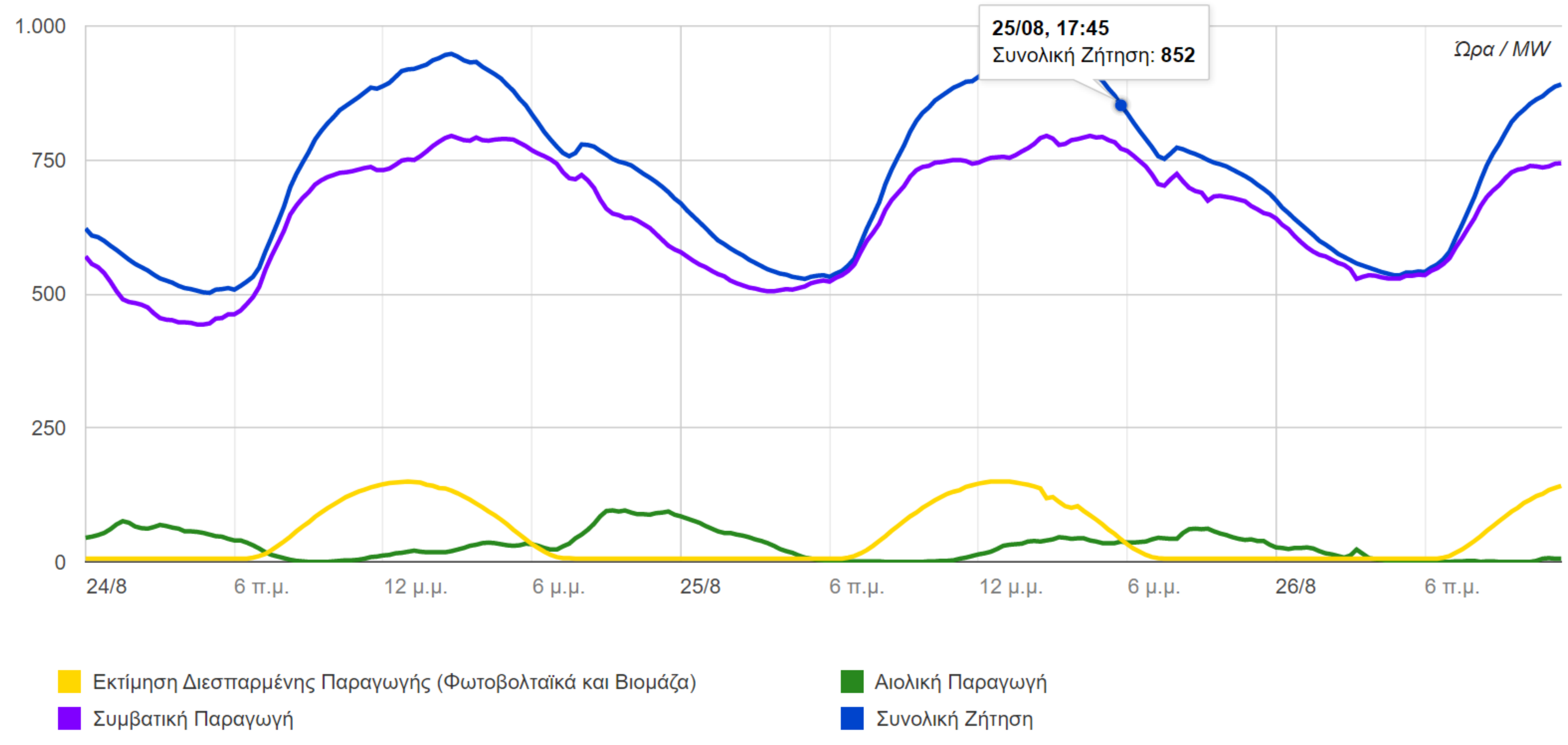
Source: Adapted from National Energy Education Development Project (public domain)

Conventional Generation in Cyprus

ΣΥΝΟΛΙΚΗ ΕΓΚΑΤΕΣΤΗΜΕΝΗ ΚΑΙ ΑΝΑΜΕΝΟΜΕΝΗ ΔΙΑΘΕΣΙΜΗ ΣΥΜΒΑΤΙΚΗ ΙΣΧΥΣ (MW) ΑΥΓΟΥΣΤΟΣ 2020						
Ηλεκτροπαραγωγός Σταθμός	Εγκαταστάσεις Συνδυασμένου Κύκλου	Ατμοστρόβιλοι	Αεριοστρόβιλοι	Μονάδες Εσωτερικής Καύσης	Ολική Ικανότητα Παραγωγής Ισχύος	
					Συνολική Εγκατεστημένη Ισχύς Ηλεκτρ. Σταθμών	Αναμενόμενη Διαθέσιμη Ισχύς Ηλεκτρ. Σταθμών
Μονής	–	–	4 x 37,5 = 150		150	128
Δεκέλειας	–	6 x 60 = 360	–	2 x 50 = 100	460	367
Βασιλικού	2 x 220 = 440	3 x 130 = 390	1 x 37,5 = 37,5	–	868	702
Ολική Ικανότητα Παραγωγής Ισχύος	440	750	187,5	100	1478	1197

***Τελευταία Αναθεώρηση:* 30 Ιουλίου 2020**

Αρχείο Ημερήσιας Παραγωγής Ηλεκτρικού Συστήματος (MW)



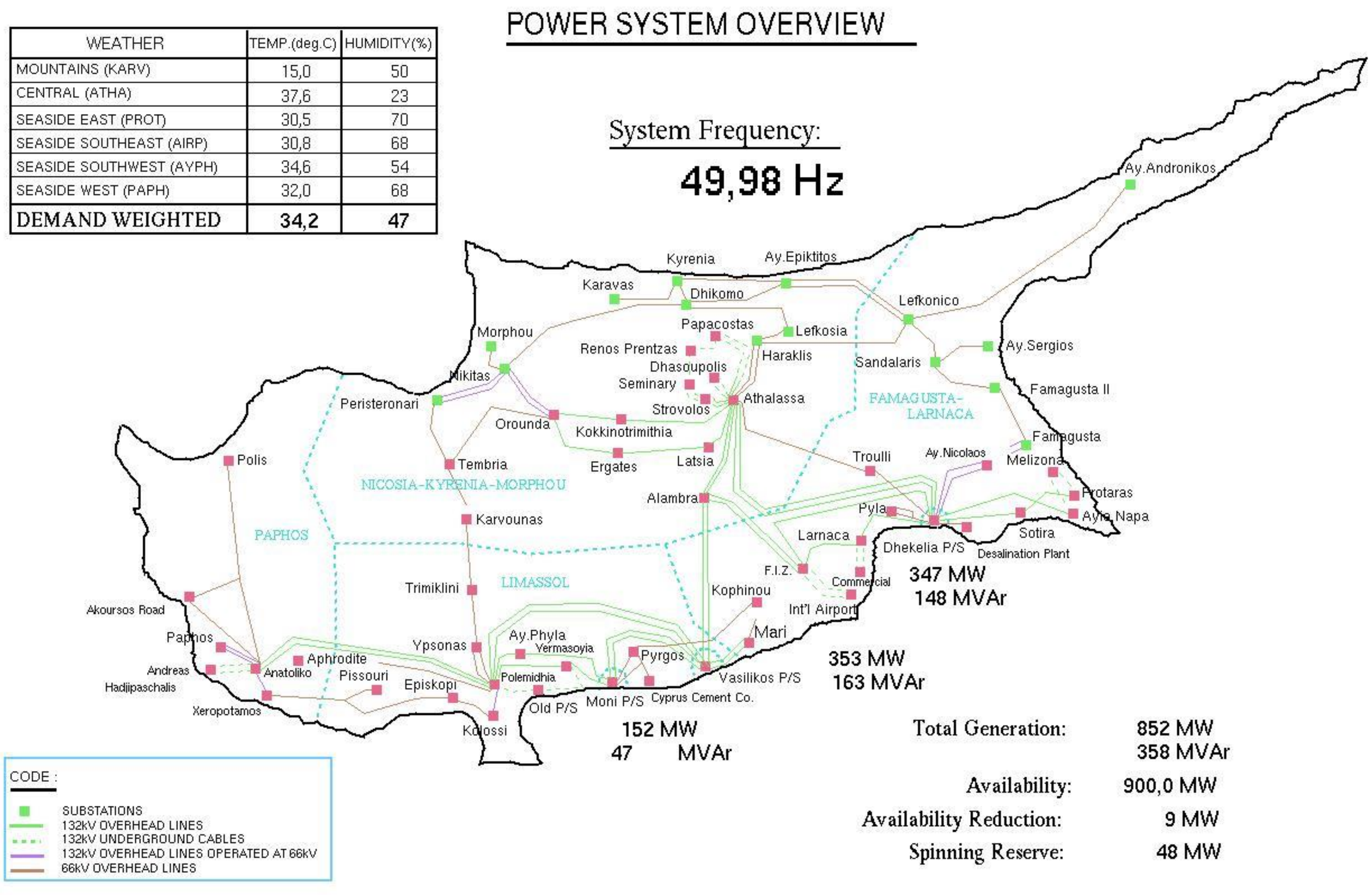
ΣΗΜΕΙΩΣΗ:

- Η συνολική ζήτηση του ηλεκτρικού συστήματος ικανοποιείται από την συμβατική, την αιολική και τη διεσπαρμένη παραγωγή

https://tsoc.org.cy/archive-total-daily-system-generation-on-the-transmission-system/

Transmission System of Cyprus

WEATHER	TEMP.(deg.C)	HUMIDITY(%)
MOUNTAINS (KARV)	15,0	50
CENTRAL (ATHA)	37,6	23
SEASIDE EAST (PROT)	30,5	70
SEASIDE SOUTHEAST (AIRP)	30,8	68
SEASIDE SOUTHWEST (AYPH)	34,6	54
SEASIDE WEST (PAPH)	32,0	68
DEMAND WEIGHTED	34,2	47



find more info: https://www.dsm.org.cy/

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Transmission System of Cyprus

THE CYPRUS TRANSMISSION SYSTEM

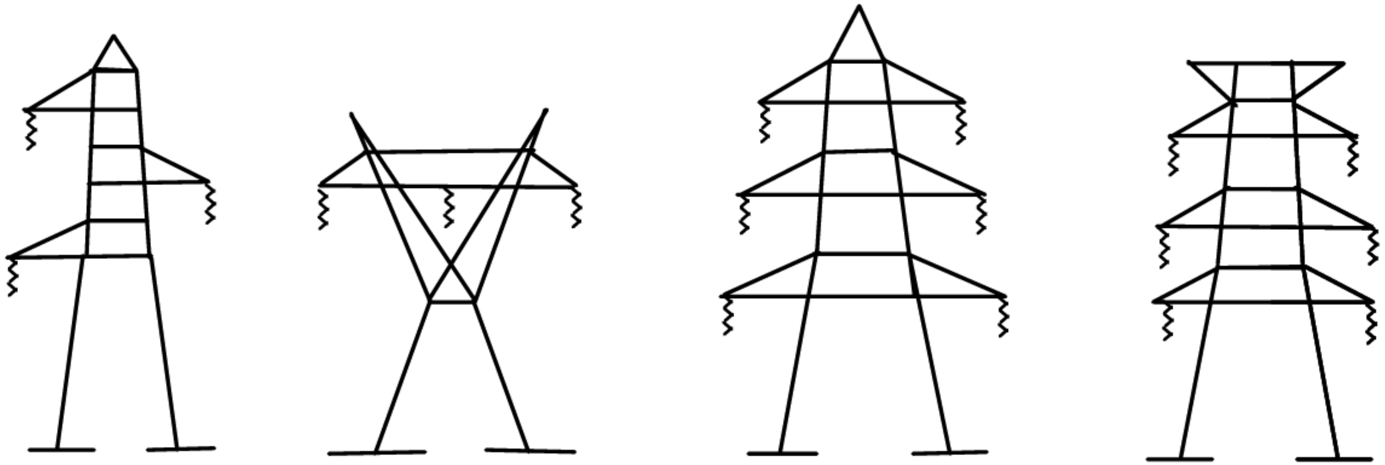
Transmission Substations: 62

Primary Substations: 9

Overhead Lines: 1150 km

Underground Cables: 212 km

General Characteristics – Poles & Towers



Single circuit Single earth wire — *Single circuit double earth wire* — *Double circuit single earth wire* — *Double circuit double earth wire*

Typical tower outlines

Suspension Tower

Tension Tower

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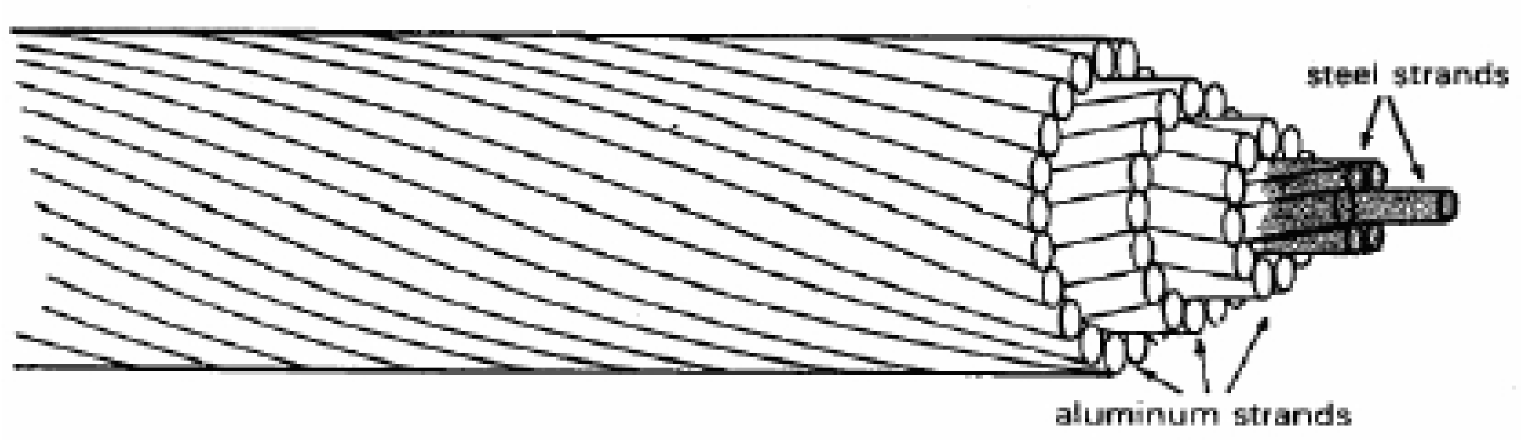
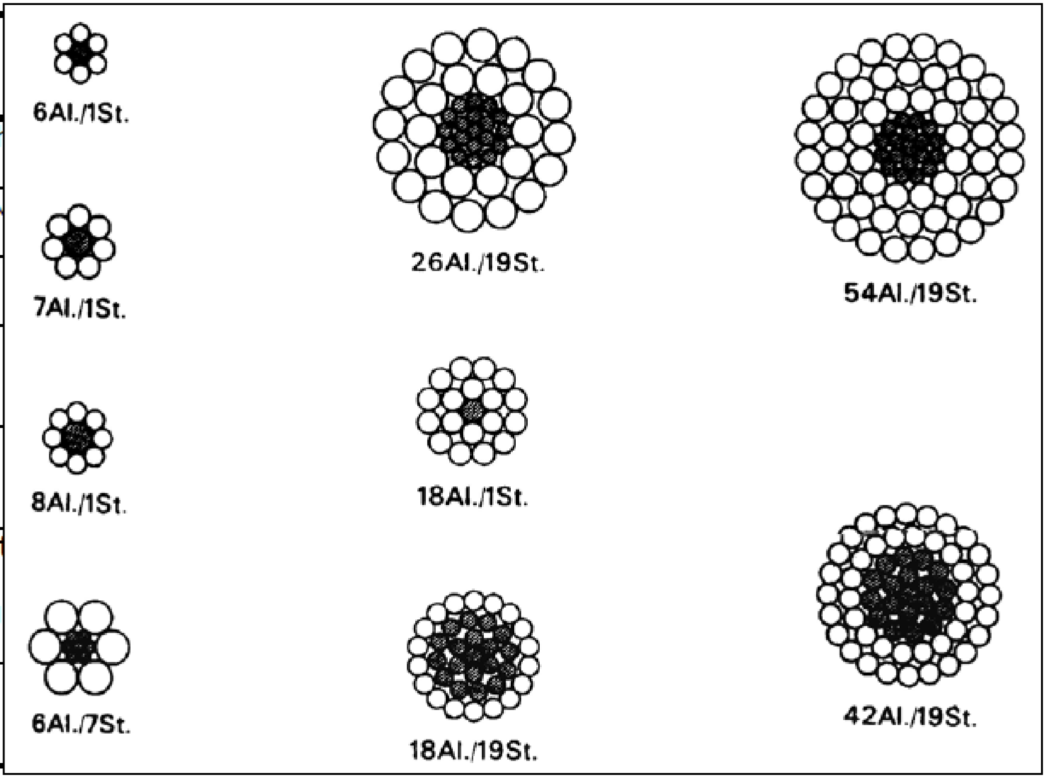
General Characteristics – Conductors



- ACSR –Aluminium Conductor Steel Reinforced
- AAAC –All Aluminium Alloy Conductors
- AACSR–Aluminium Alloy Conductors Steel Reinforced
- ACAR–Aluminium Conductor Alloy Reinforced

General Characteristics – Conductors

Parameter	Importance
Relative conductivity (%)	Minimises resistive losses. High value desired.
Mass resistivity at 20°C (Ωkg/km)	Provides good resistance for lo mass. Low value desired.
Density (kg/m^3)	System mass. Low value desired.
Resistance Temperature Coefficient (°C^{-1})	Change in resistance as a function of temperature. Low value desired.
Coefficient of linear expansion (°C^{-1})	Partly determines sag as conductors thermally expand. Low value desired.
Ultimate tensile stress (MN/m^2)	Imposes maximum tension that can be imposed on conductor and therefore important for sag High value desired.
Modulus of elasticity (MN/m^2)	Determines expansion of conductor under normal load. High value desired.

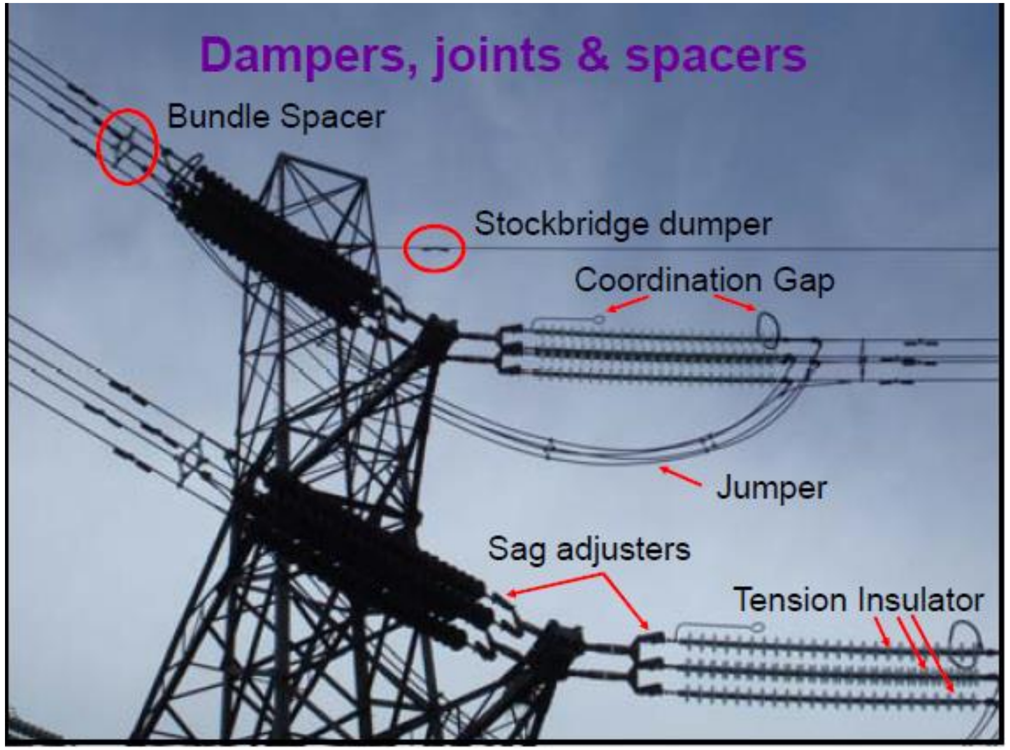


Code name	Stranding pattern	Al area (mm^2)	Steel area (mm^2)	Diameter (mm)	Mass (kg/km)	Breaking load (kN)	Resistance (Ω/km)
Horse	12/7/2.79	73.4	42.8	14.0	538	61.2	0.3936
Lynx	30/7/2.79	183.4	42.8	19.5	842	79.8	0.1441
Zebra	54/7/3.18	429.9	55.6	28.6	1621	131.9	0.0674
Dove	26/3.72 + 7/2.89	282.0	45.9	23.6	1137	99.9	0.1024

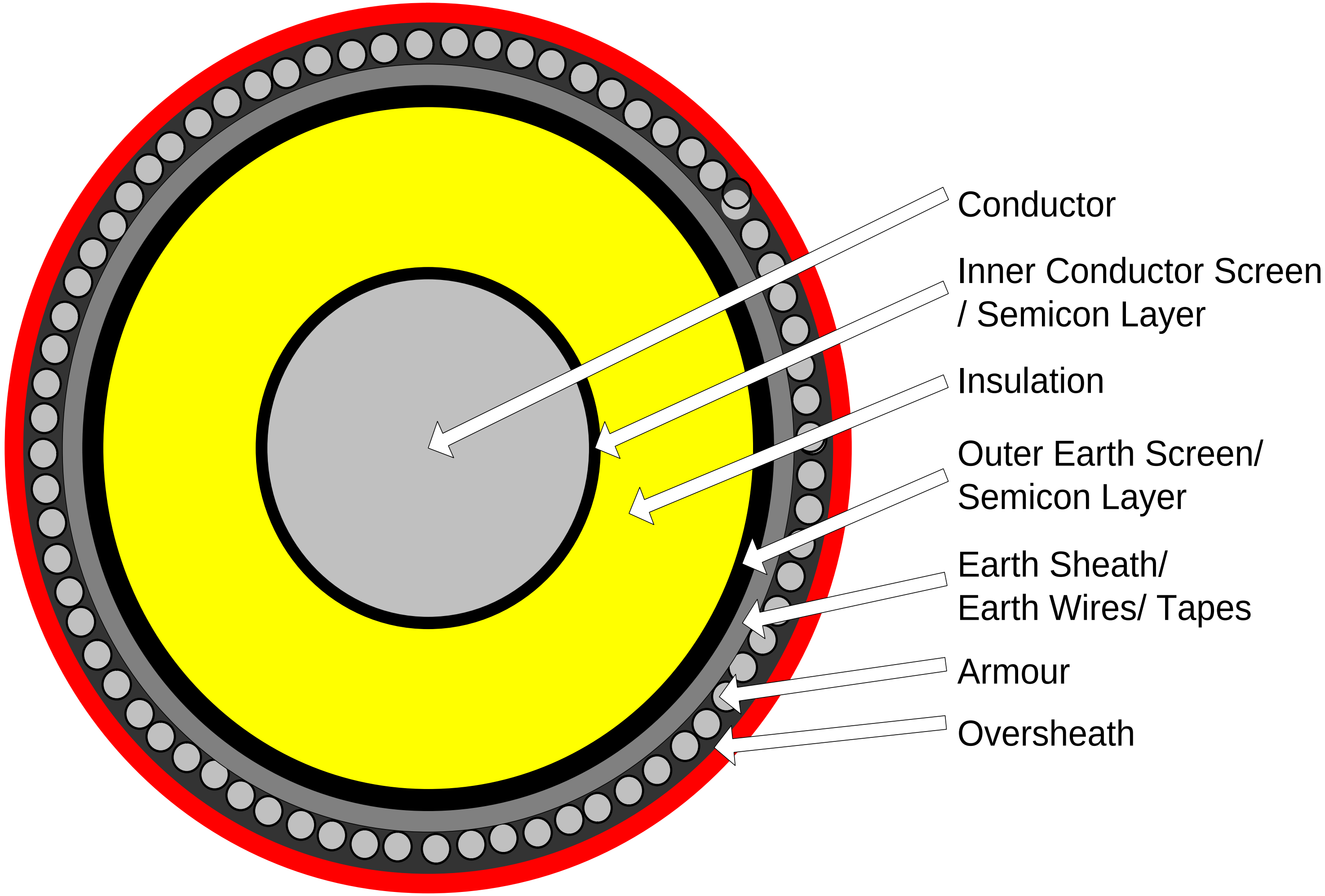
Conductor Bundles

Clamps, Dampers and Joints

Overhead line Stockbridge damper



Power Cable Components



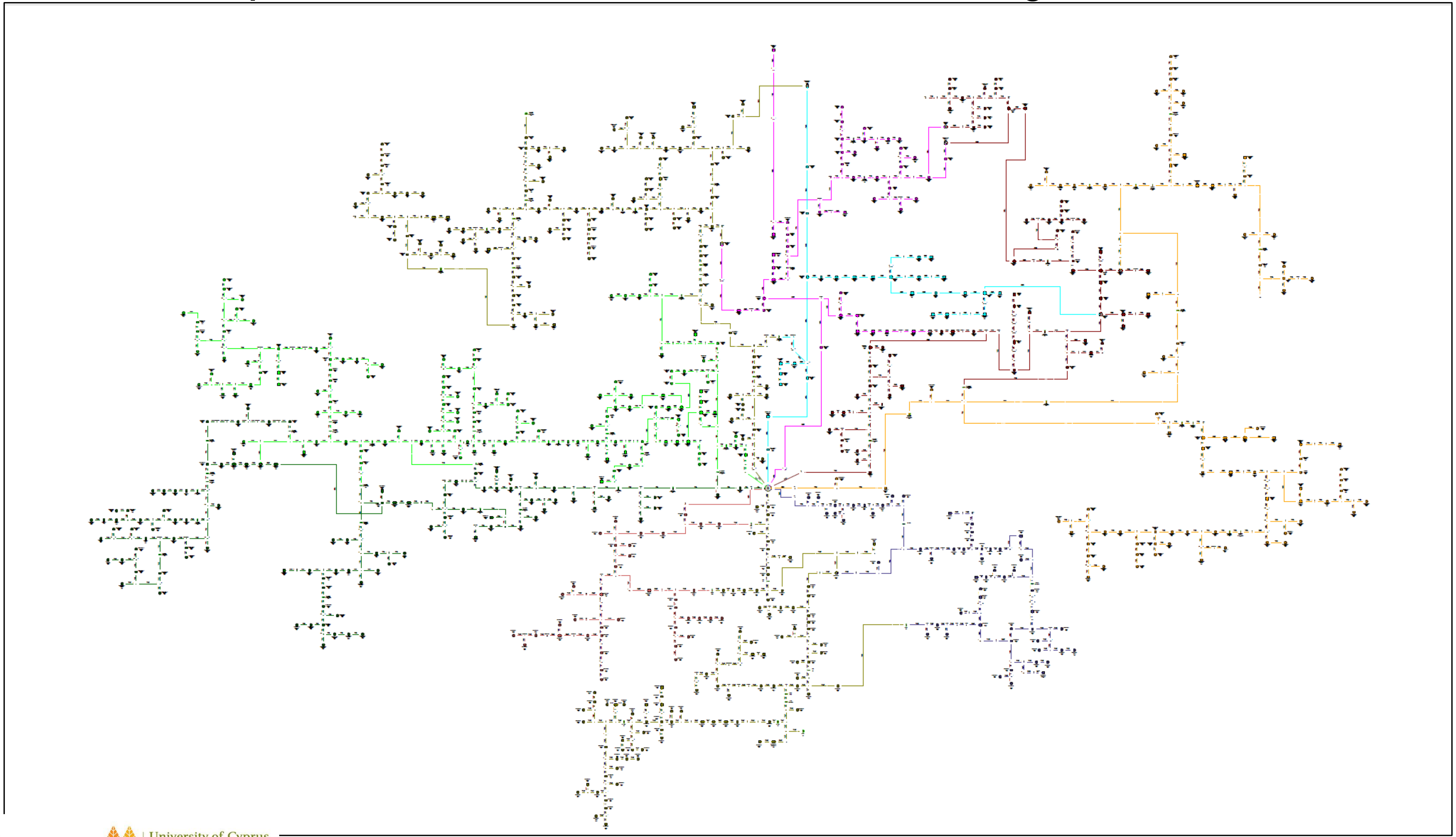
Power Cable Installation

OHL Vs. Cables

Disadvantages	Advantages
More expensive than an equivalent overhead line circuit (especially at EHV levels)	No visual impact except that which occurs during installation
The time to repair a cable fault is generally longer than the time to repair an overhead line fault (fault location, excavation and jointing can take time)	Provide relatively reliable circuits as they are not exposed to lightning or affected by wind borne debris
Difficulty relating to installation in already crowded rights of way	Protected from vandalism

Distribution – Medium voltage (11 kV to 0.4 kV)

Example of MV network at ALAMBRA – DIgSILENT model



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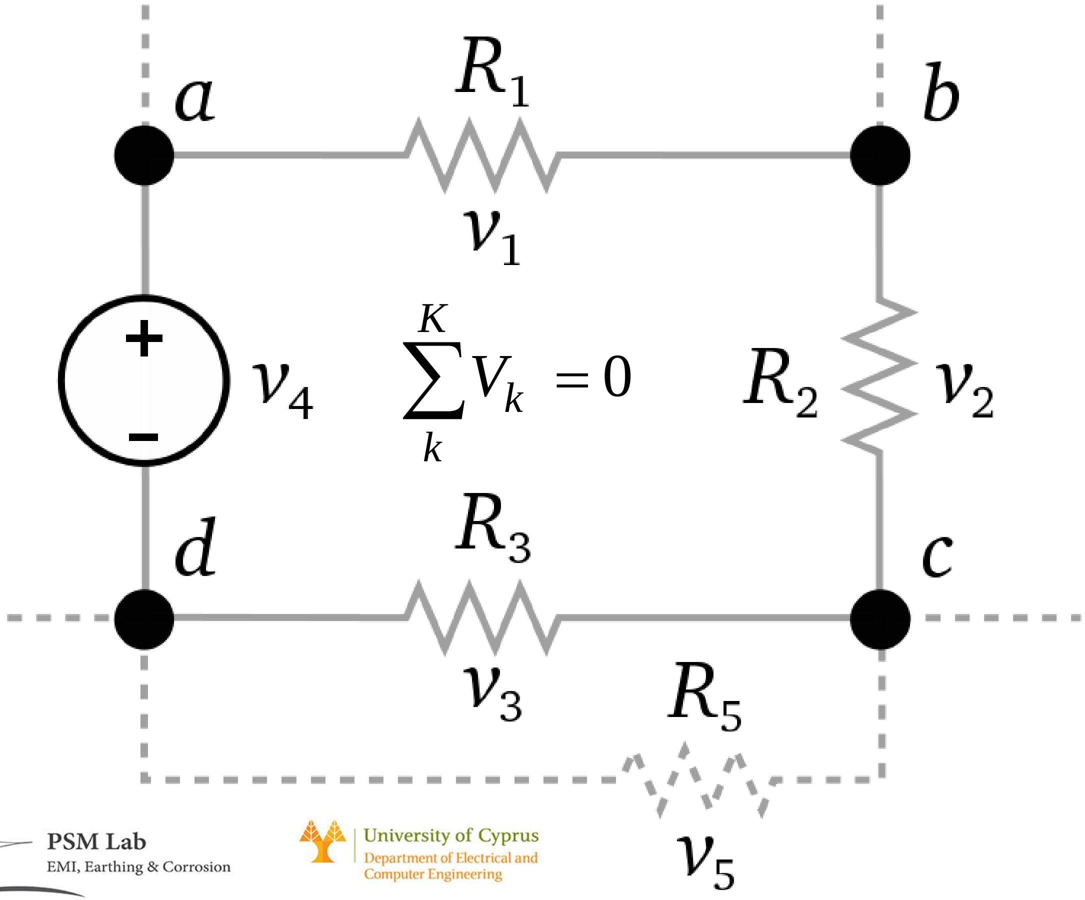
KVL and KCL

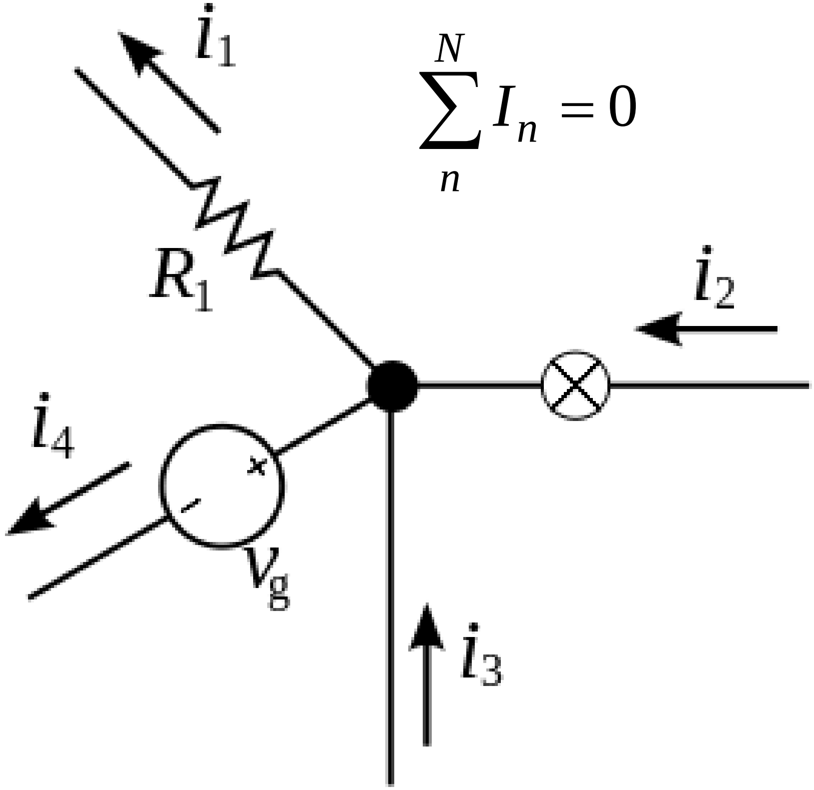
KVL:

The directed sum of the electrical potential differences (voltage) around any closed loop is zero

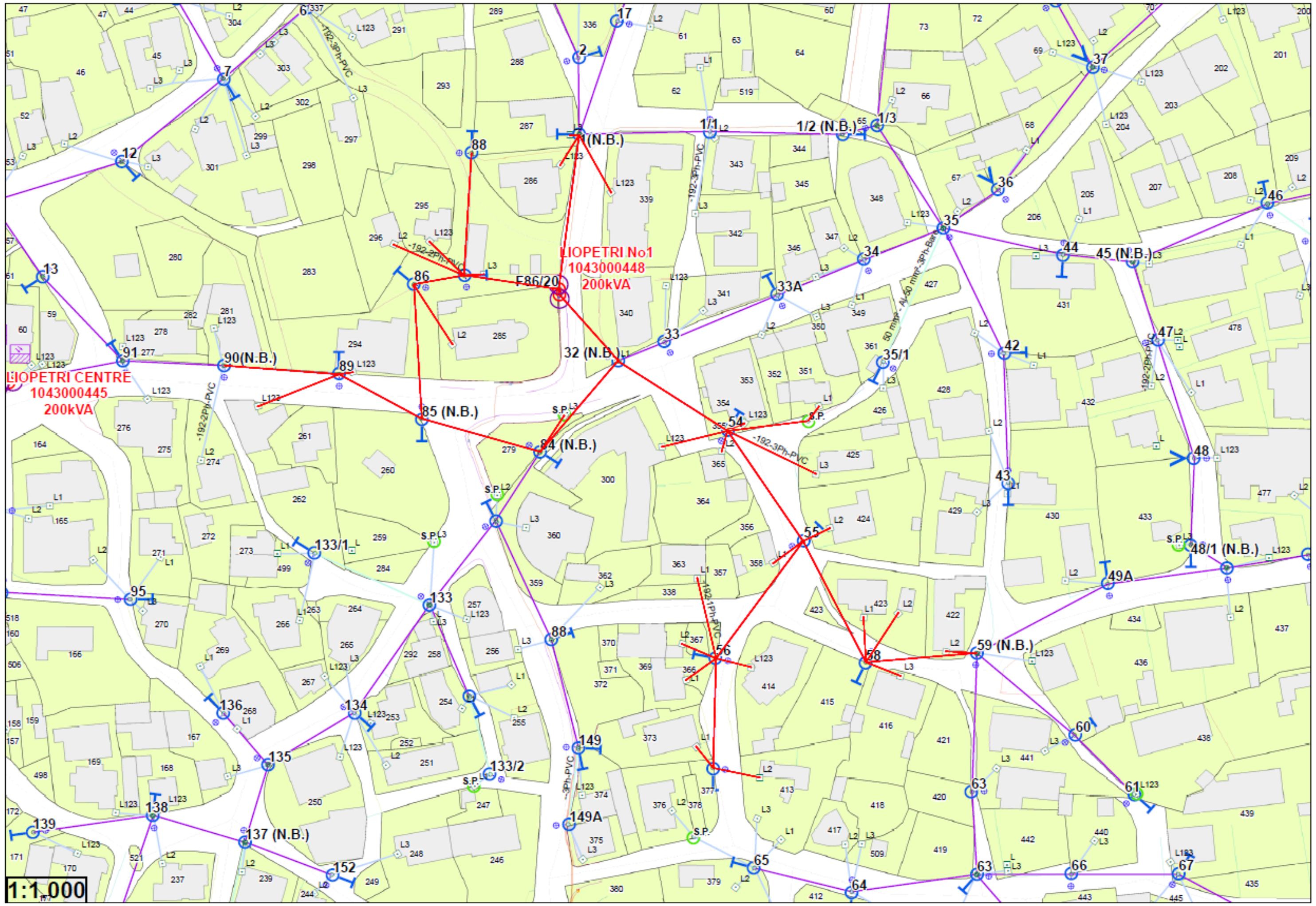


KCL:

The algebraic sum of currents in a network of conductors meeting at a node is zero



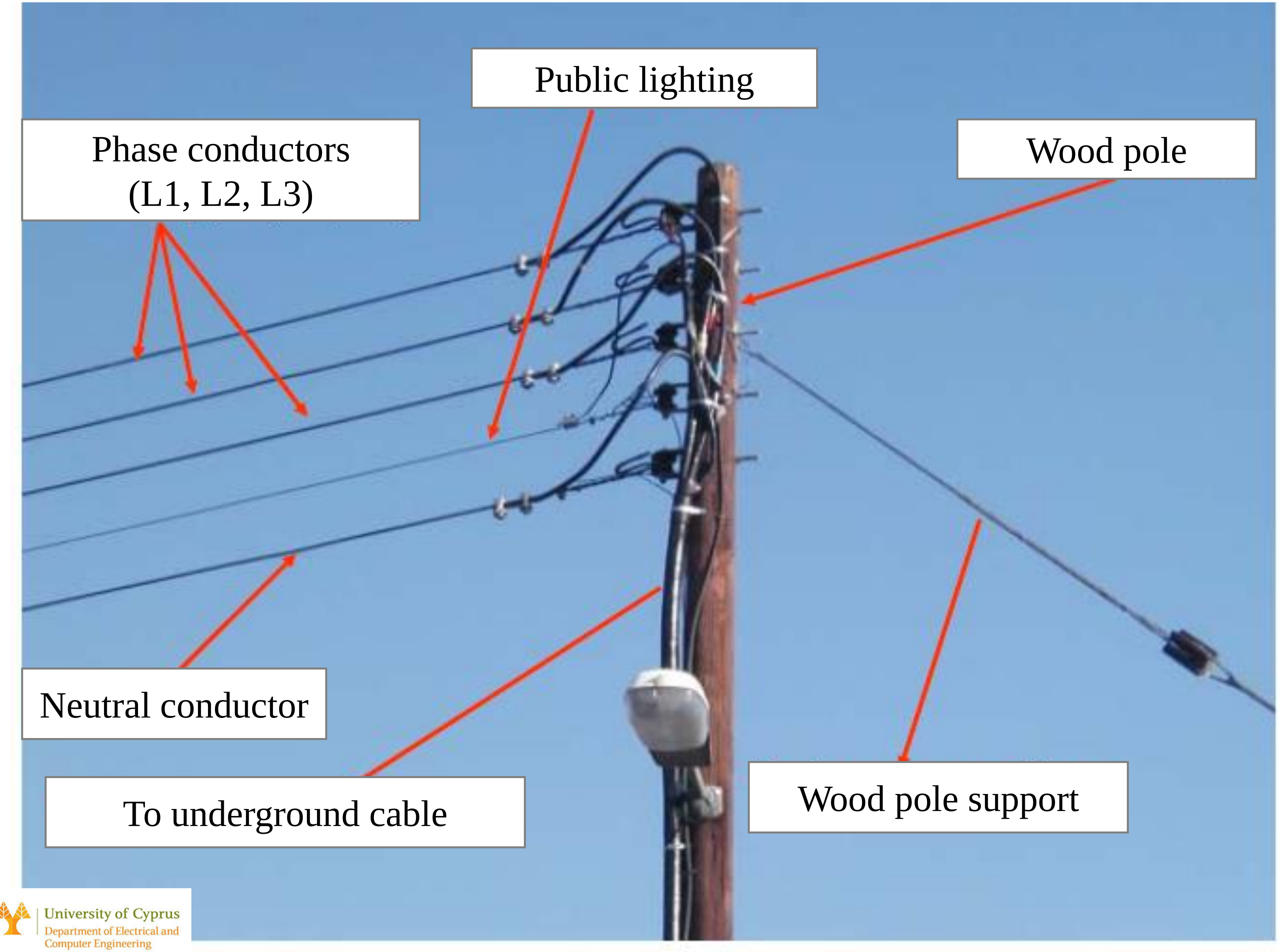
Example of LV network at Liopetri Centre – ArcGIS



Service points	26
Total number of customers	52
Residential customers	23
Commercial customers	29

✓ ArcGIS software (available to EAC) is used as a very effective off-line tool that can facilitate the visualization of LV networks (that are not monitored on a real-time basis)

Distribution – Low voltage (<1 kV)



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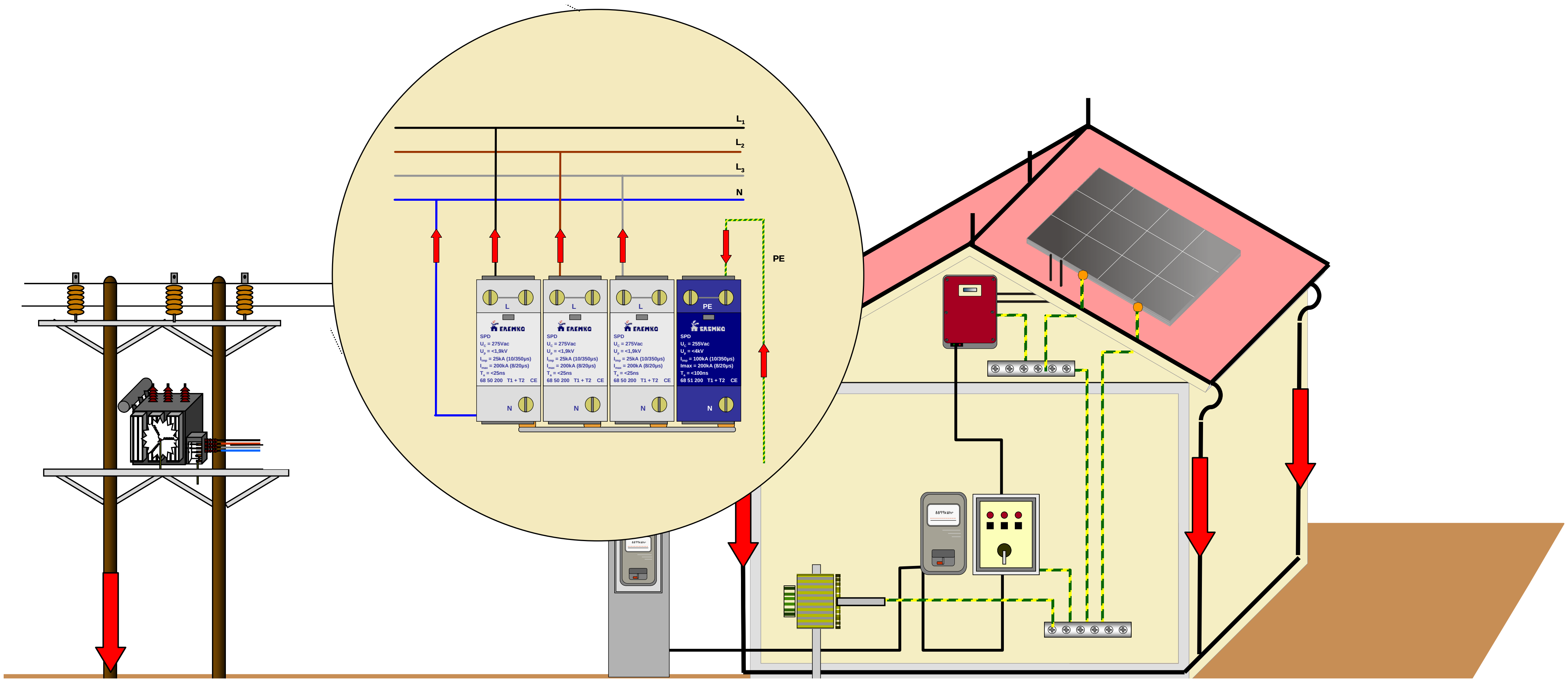
Electricity Supply at Domestic Level



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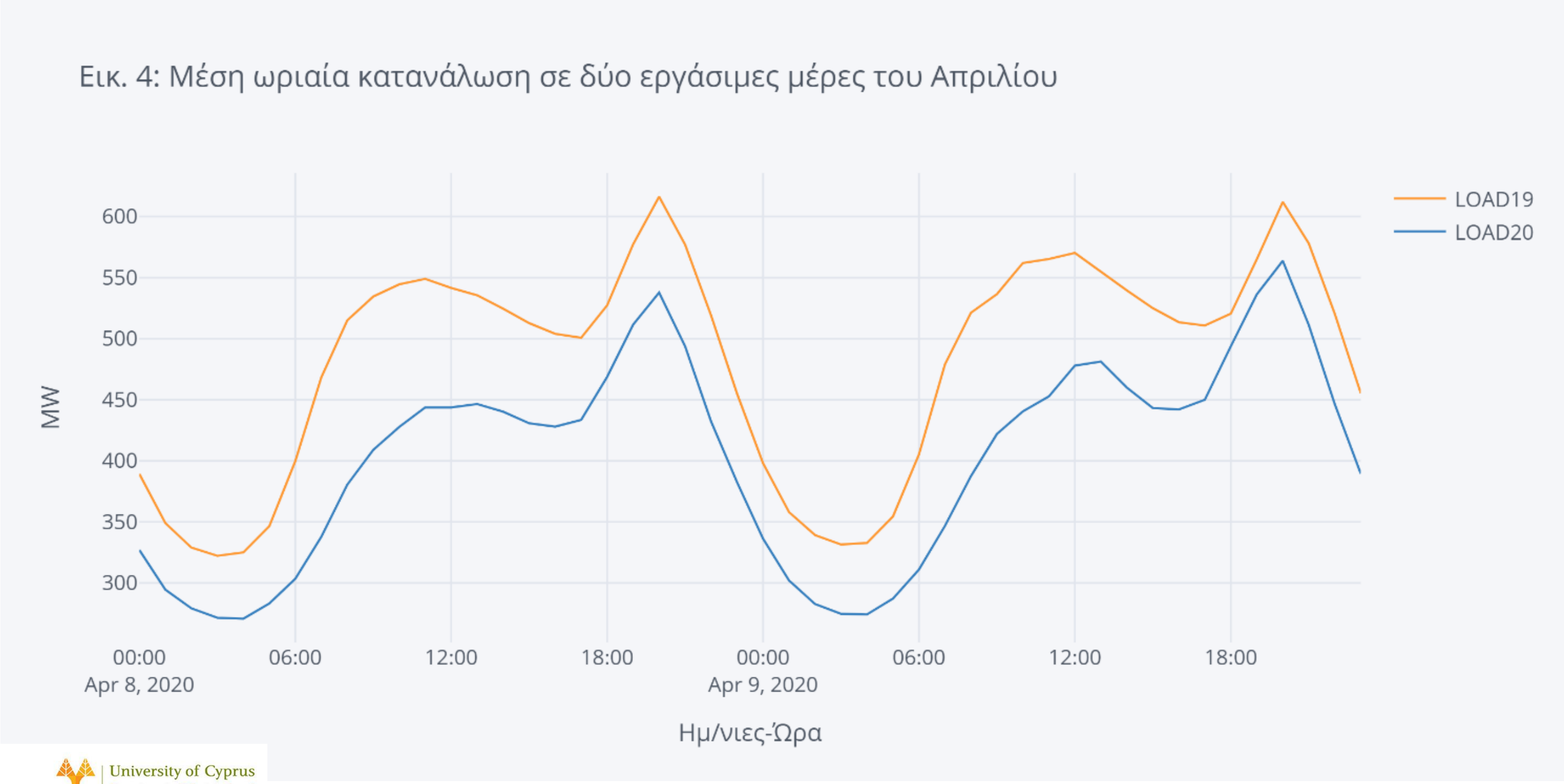
Auxiliary slides – Energy consumption and profiles

Η επίδραση του κορονοϊού στην ενεργειακή συμπεριφορά των Κυπρίων

https://www.cut.ac.cy/news/article/?contentId=254240



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Auxiliary slides – Energy consumption and profiles