Thermochemical Power Group

Sustainable Energy

Mod.1: Fuel Cells & Distributed Generation Systems

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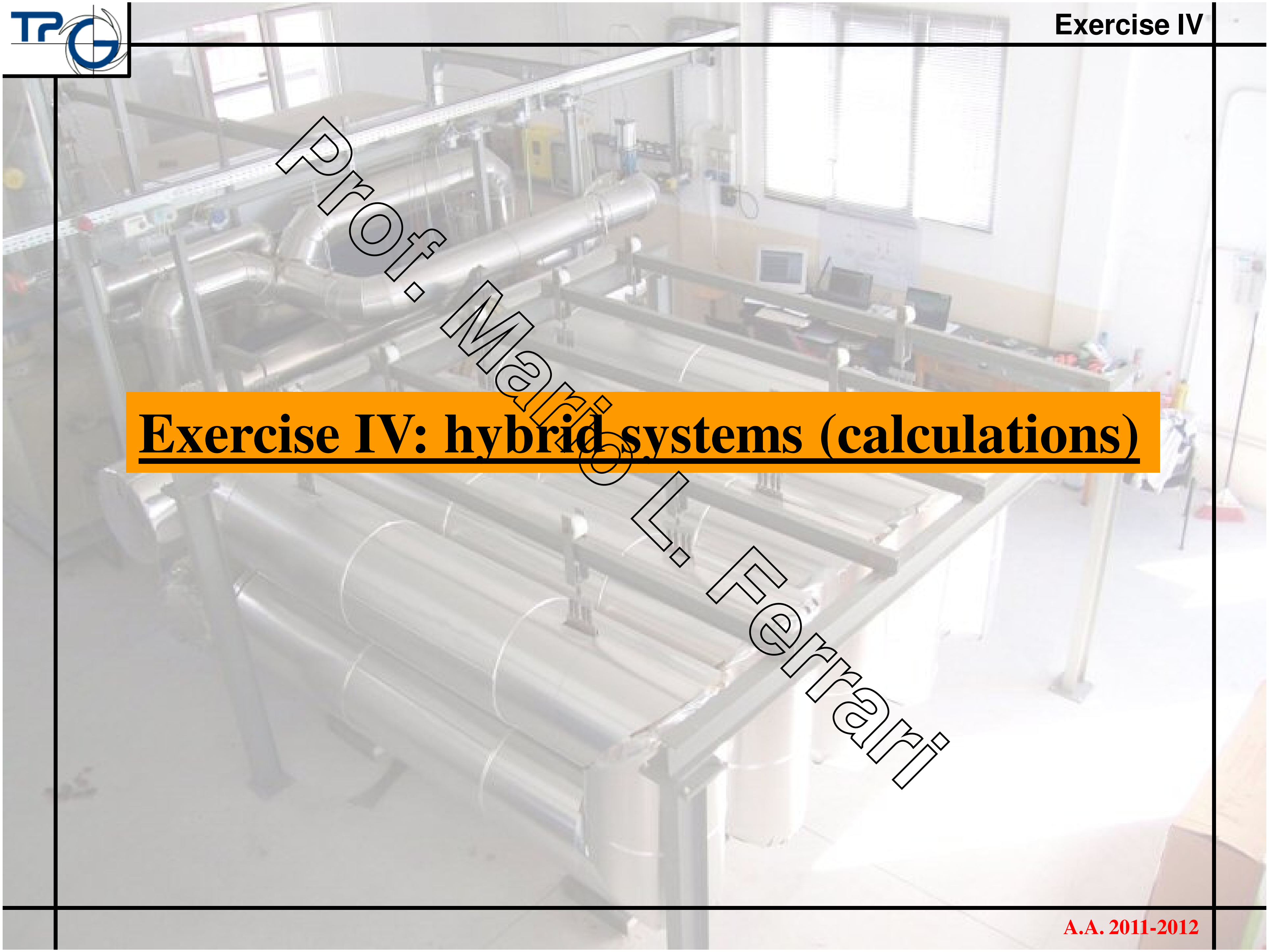
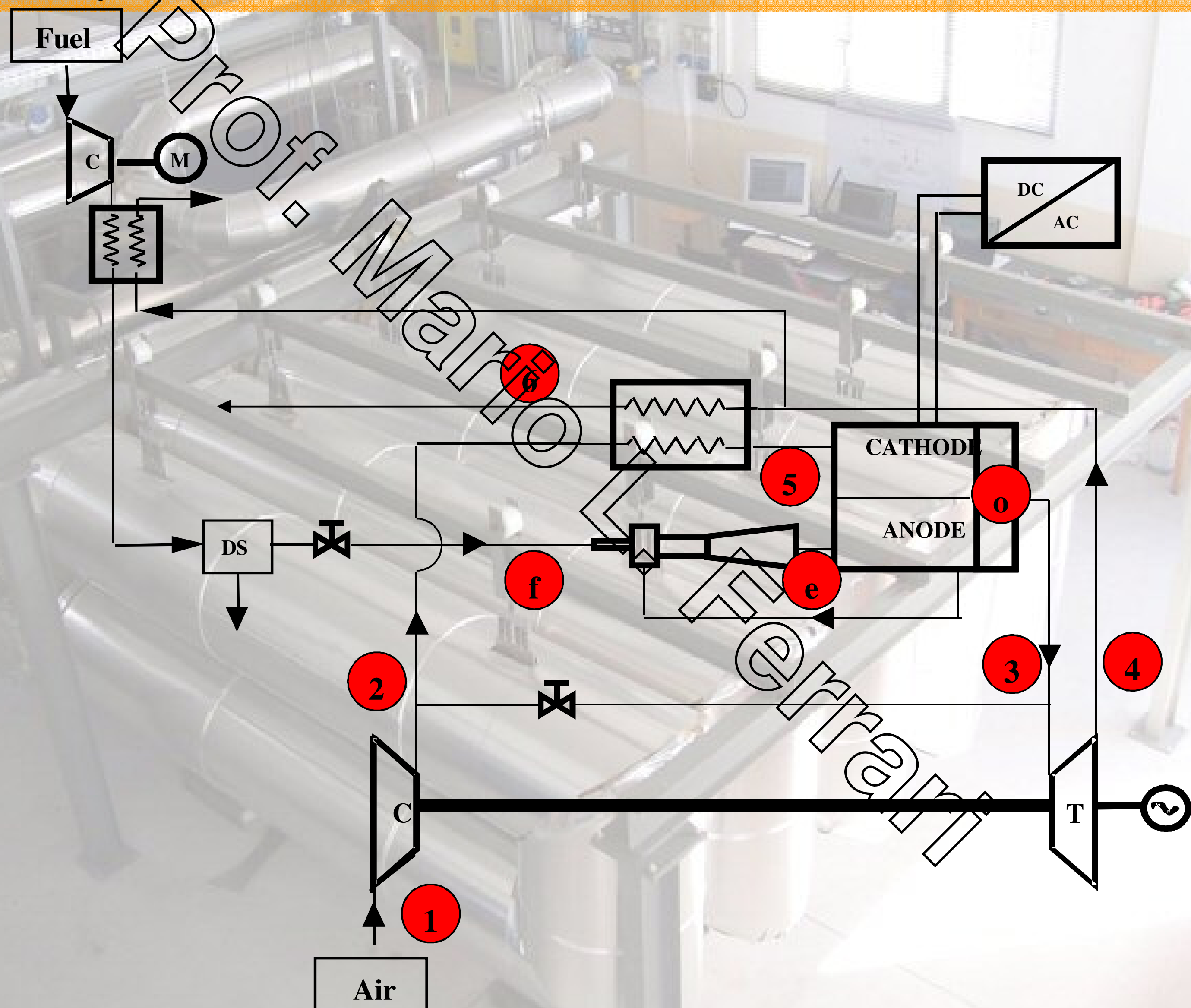


Exercise IV: hybrid systems (calculations)

Exercise 1: Calculate the design performance (power and efficiency) for the tubular SOFC based hybrid system shown in the figure below. Known data:

- **Compressor inlet : pressure, temperature, air humidity.**
- **Compressor : mass flow rate, efficiency, pressure ratio.**
- **Recuperator: effectiveness, pressure losses.**
- **Fuel data (point f): pressure, temperature, chemical composition (LHV_f).**
- **Anodic ejector data: recirculation ratio.**
- **Fuel cell data: fuel utilization factor, coefficients for polarizations, heat loss, pressure losses, temperature (T_{cell}), effectiveness of pre-heating tube.**
- **Off-gas burner: combustion efficiency, pressure loss.**
- **Expander: efficiency.**
- **Outlet duct: pressure loss.**
- **Electrical : power conditioning component efficiency.**
- **Machine shaft: mechanical efficiency.**

Plant layout:



Solution (1/2):

1. Calculation of compressor outlet temperature: $T_2=T_1+(1/\eta_c)*T_1*(\beta_c^{\theta}-1)$
2. Calculation of compressor power: $P_c = m_a*c_{p\_a}*(T_2-T_1)$
3. **Choice of a realistic value of TOT: T_4.**
4. Calculation of recuperator outlet temperature: $T_5 = T_2 + \varepsilon*(T_4-T_2)$
5. Calculation of cathode inlet pressure: $p_5 = p_2 - \Delta p_{2-5}$
6. Calculation of off-gas burner inlet pressure: $p_o = p_5 - \Delta p_{5-o}$
7. **Choice of a realistic fuel mass flow rate (m_f).**
8. **Choice of a realistic anode outlet composition.**
9. Calculation of ejector outlet mass flow rate: $m_e = m_f + m_f*(Rec.Ratio)$
10. Calculation of ejector outlet composition (mixing) and temperature.
11. Calculation of ejector outlet pressure: $p_e = p_o + \Delta p_{e-o}$
12. Minimization of free Gibbs energy for reforming and shifting.
13. Calculation of reformer outlet composition and temperature.
14. Calculation of current from fuel utilization factor (U_f).
15. Calculation of anode outlet composition and **iteration from point 8**.
16. Calculation of pre-heating tube outlet temperature ($T_{cath\_out} = T_{cell}$).
17. Calculation of Nernst's potential: $E = E^{\circ} + (RT/2F)\ \ln [P_{H_2}/P_{H_2O}] + (RT/2F)\ \ln [P_{O_2}^{1/2}]$
18. Calculation of voltage losses and real potential.

Solution (2/2):

19. Calculation of cathode outlet composition.
20. Calculation of T_{cell} (energy balance) and **iteration from point 7**.
21. Calculation of combustor outlet: temperature, pressure ($p_3 = p_o - p_{o\text{-}3}$), composition, mass flow rate ($m_3 = m_a + m_f$).
22. Calculation of turbine outlet pressure: $p_4 = p_{amb} + \Delta p_{outlet\_duct} + \Delta p_{4\text{-}6}$
23. Calculation of turbine expansion ratio: $\beta_t = p_3/p_4$
24. Calculation of TOT ($T_4 = T_3 - \eta_t * T_3 * (1 - 1/\beta_t^{\theta})$) and **iteration from point 3**.
25. Calculation of turbine power: $P_t = m_3 * c_{p\_e} * (T_3 - T_4)$
26. Calculation of SOFC power: $P_{SOFC} = V * I * \eta_{el\_SOFC}$
27. Calculation of machine power: $P_{mGT} = (P_t - P_c) * \eta_m * \eta_{el\_mGT}$
28. Calculation of plant efficiency: $\eta_g = (P_{SOFC} + P_{mGT} - P_{aux})/(m_f * LHV_f)$