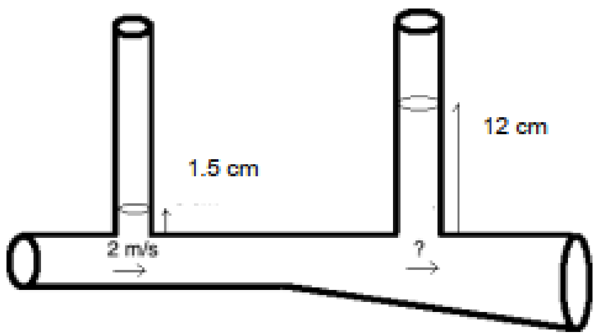
HW-2: Energy Storage and Transport

By: Yash Shailendra Gokhale (ysg)

Q1]



Consider the point on the LHS as '1' and that on the RHS as '2'.

a)

Pressure at both the points is the same

Applying Bernoulli's equation for an ideal case:

$\frac{1}{2}\varrho v_1^2 + \varrho g h_1 + P_1 = \frac{1}{2}\varrho v_2^2 + \varrho g h_2 + P_2$

Given $P_1 = P_2$:

$\frac{1}{2}\varrho v_1^2 + \varrho g h_1 = \frac{1}{2}\varrho v_2^2 + \varrho g h_2$

Substituting:

$\frac{1}{2}v_1^2 + gh_1 - gh_2 = \frac{1}{2}v_2^2$

$\frac{1}{2} * 2^2 + 9.8 * 0.015 - 9.8 * 0.12 = \frac{1}{2}v_2^2$

$v_2 = 1.39\frac{m}{s}$

b)

To find the work done by fluid against friction per unit mass:

$W = g * h_L$, where h_L is the head loss due to friction

$\frac{1}{2}\varrho v_1^2 + \varrho g h_1 + P_1 = \frac{1}{2}\varrho v_2^2 + \varrho g h_2 + P_2 + \varrho g h_L$

Given that: $P_2 - P_1 = 1.5\ Pa$

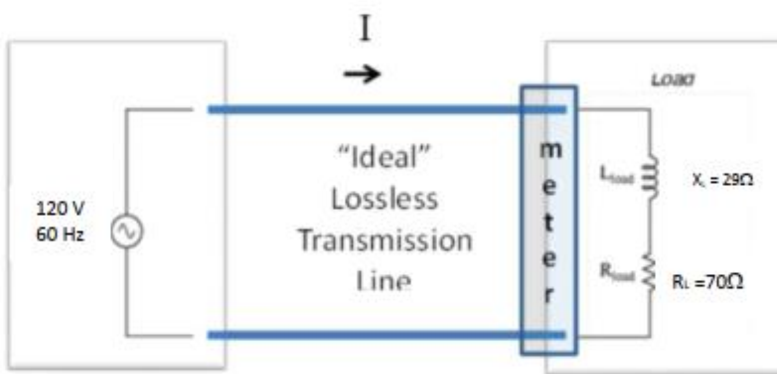
Substituting:

$\frac{1}{2} * 400 * 2^2 + 400 * 9.8 * 0.015 = 1.5 + \frac{1}{2} * 400 * 1.39^2 + 400 * 9.8 * 0.12 + 400 * W$

Evaluating the same:

$W = 1.2 * 10^{-3} \frac{J}{kg}$ (Work done by fluid against friction per unit mass)

Q2]



Impedance: $Z = \sqrt{R^2 + (X_L - X_C)^2} = 99.81$

a)

For components in series: $i = \frac{V_{RMS}}{\sqrt{R^2+X_L^2}}$

Given: $V_{RMS} = 1000\ V$ | $X_L = 29\ ohms, R_L = 95.5\ ohms$

Substituting: $i = \frac{1000}{\sqrt{99.81^2+29^2}} = 10.012\ A$

b)

Since the circuits are in series, voltages will add up.

$V_{load} = \sqrt{V_R^2 + V_L^2}$

$V_R = 10.012 * 95.5 = 956.146\ V$

$V_L = 10.012 * 29 = 290.35\ V$

$V_{load} = \sqrt{956.146^2 + 290.35^2} = 999.26\ V$

By Kirchoff's Law: $V_{RMS} = V_{load}$

c)

Power across resistive load: $P_R = i^2 R = 10.012^2 * 95.5 = 9572.93\ W$

d)

Power across inductive load: $P_L = i^2 X_L = 10.012^2 * 29 = 2906.96\ W$

e)

Apparent power: $P_A = i^2 Z = 10.012^2 * 99.81 = 10004.97\ W$

f)

Power factor, $PF = \frac{True\ power}{Apparent\ power} = \frac{9572.93}{10004.97} = 0.9568$

The value seems to be a reasonable power factor for the values of the reactance and inductance present in the circuit. However, in practical cases, reactive power accounting to 95% of the apparent power seems to be a comparatively higher value.

g)

The capacitor needs to be put on the customer side (right) as it can change the value of the impedance. In this way, the apparent power can be reduced.

The new circuit would have the capacitor in parallel. For simplicity, assume that R is the resistance (net) of the transmission line and X is the capacitor resistance.

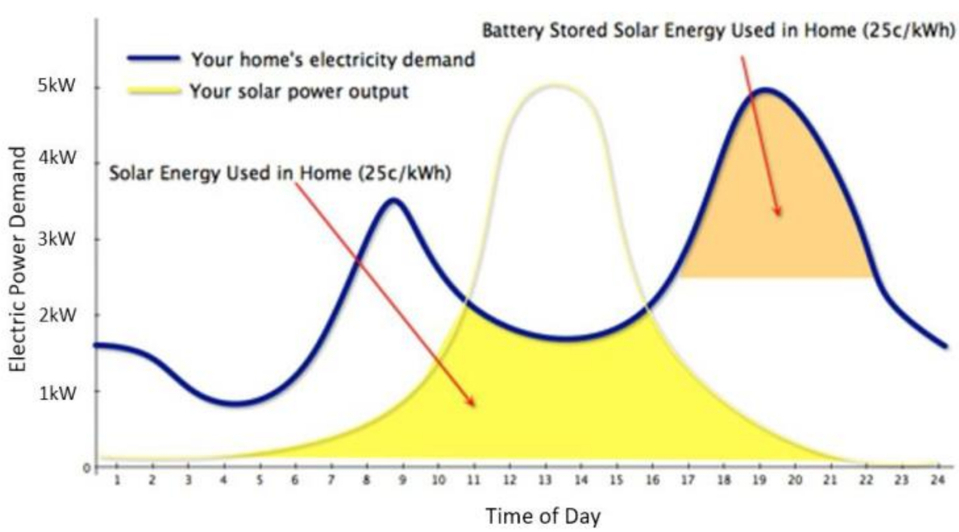
$Z = \frac{1}{\frac{1}{R}+\frac{1}{X_C}}$

$X_c = \frac{1}{2\pi f C}$

Apparent power, $AP = i^2 Z = i^2 \frac{1}{\frac{1}{R}+\frac{1}{X_C}} = i^2 \frac{1}{\frac{1}{R}+2\pi f C}$

From the relation of apparent power, it can be observed that as C increases, the apparent power decreases. From the given options: $C = \mathbf{1000}\ \mu C$, which would result in lowest impedance and thereby lowest apparent power.

Q3]



The area shaded as the battery stored solar energy can be approximated as an area of the parabola as follows:

$A = \frac{2}{3} * M * N$ Where $M = 23 - 16.5 = 6.5$ | $N = 5 - 2.5 = 2.5$

Area under the curve, $A \sim 11\ kWh$

a.

The recommended battery storage system ratings to satisfy the minimum criteria can be of 12 kWh for energy. Also, recommended power is: 2 kW (Assuming 6 hours of operation per day).

b.

Number of Tesla Powerwall(s) needed=1

Since A single powerwall can store upto 13.5kWh.

c.

Cost of Tesla powerwall, $C_{tesla} = 7100\ \$$

To calculate the amount saved from the electricity per year:

$C_{solar} = 0.25 \frac{\$}{kWh} * 11\ kWh * \frac{365}{year} = 1003.75 \frac{\$}{year}$

Number of years to recover the cost: $N_{years} = \frac{C_{tesla}}{C_{solar}} = \frac{7100}{1003.75} \sim \mathbf{7.07\ years}$

It would roughly take 7 years for the landlord to recover his money.

Q4]

N: Distance

Case 1A: HVDC model:

LNG costs, $C_{LNG} = Capacity * (Losses + 1) * Cost$

Transmission cost, $C_{Transmission} = 0.114N + 140\ million\ \$$

Monthly cost, $C_{monthly} = P * \frac{\frac{i*(1+i)^N}{(1+i)^N - 1}}{12}$

Total cost, $C_{total} = C_{LNG} + C_{monthly}$

Case 1B: HVAC model:

LNG costs, $C_{LNG} = Capacity * (Losses + 1) * Cost$

Transmission cost, $C_{Transmission} = 0.533N + 20\ million\ \$$

Monthly cost, $C_{monthly} = P * \frac{\frac{i*(1+i)^N}{(1+i)^N - 1}}{12}$

Total cost, $C_{total} = C_{LNG} + C_{monthly}$

Case 2A: Medium pressure pipeline

LNG costs, $C_{LNG} = Capacity * Cost$

Pipeline cost for 22 inch diameters: $C_{pipe} = (1555 * (22)^{*}2.44) * N$

Equipment cost is calculated using Quotient function in Excel.

Case 2B: High pressure pipeline

LNG costs, $C_{LNG} = Capacity * Cost$

Pipeline cost for 18 inch diameters: $C_{pipe} = (1555 * (18)^{*}2.44) * N$

Equipment cost is calculated using Quotient function in Excel.

Results:

The monthly cost was calculated from 10 to 1990 mile and then plotted for visualization as follows:

Solutions:

A.

The monthly cost of HVDC follows a positive linear trend, with the cost increasing as the distance increases. Thus, lower the distance, lower is the cost.

Hence, for 0-10 miles, the cost of HVDC is the lowest.

B.

Similar to the HVDC case, HVAC also follows a positive linear trend, with the cost increasing as the distance increases. Thus, lower the distance, lower is the cost.

Hence, for 0-10 miles, the cost of HVAC is the lowest.

C.

From the analysis, it can be seen that the cost for Case 2-A is always lower than that of Case 1-A, due to the linear nature of the curves.

D.

From the analysis, it can be seen that the cost for Case 2-B is always lower than that of Case 1-A, due to the linear nature of the curves.

E.

The breakeven points will change when the price of natural gas changes. In all the four cases presented here, calculating the total energy cost requires a component of natural gas price (if global LNG price is considered). The exact formula is as follows:

Monthly LNG Cost, $C_{monthly} = Energy_{monthly} * (1 + Loss) * C_{NG}$

As the monthly natural gas cost adds up to the total monthly cost, an increase in LNG price will lead to an increase in the total monthly cost, thereby shifting the breakeven point to the higher side.

Thus, natural gas prices have a linear influence on the break-even points (in the sense that, an increase in LNG cost will lead to upward shift of breakeven point), if global natural gas prices are featured in the calculations of the monthly LNG cost.

If the cost is solely dependent on the nominal LNG cost, there is no change in the breakeven point.

F.

Both the overhead electric transmission and underground gas pipes have their own safety concerns. However, a general public perception would favor underground gas pipes. The overhead electric transmission is visible to public and may cause them to pay further attention to its efficacy. In case of overhead electric transmission, faults in wiring and inaccuracies in meter might be the prime causes of concerns and need to be addressed immediately. Short circuiting and fires may cause loss of life and also lead to power outages for a very long time. In case of underground gas pipes, the primary cause of concern is that leakages in the pipes, which go unnoticeable could lead to higher order damages, the restoration of which could take a much longer time than the overhead electric transmission. Thus, both the methods have its own pros and cons and superiority should be determined on case to case basis.