Examples of static optimization

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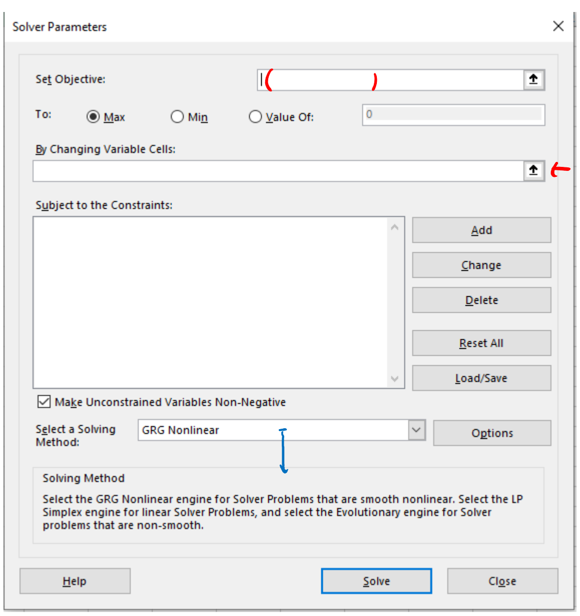

optimization formulation

maximize (or minimize) → f objective

by changing x variables

subjected to: constraints

method

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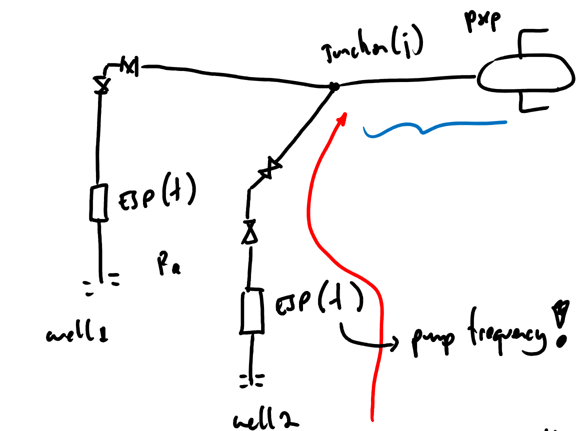
Setting up the optimization: optimizer «outside» the model

2 well ESP lifted in a network

no choke

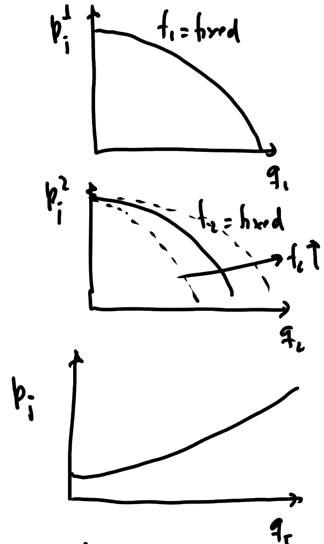


$$p_j^1 = F_1(q_1, f_1)$$

F: IPR, TPR, ESP, FPR

$$p_j^2 = F_2(q_2, f_2)$$

$$p_j = F_3(q_1 + q_2)$$



How to solve this system given f_1, f_2

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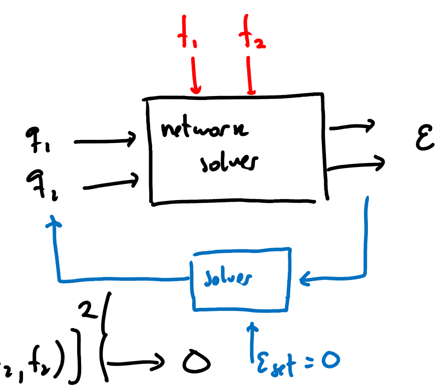
Setting up the optimization: optimizer «outside» the model

all p_j must be equal!

given f_1, f_2

change q_1, q_2 to drive

$$\underbrace{\left\{ \underbrace{\left[F_1(q_1,f_1) - F_2(q_2,f_2)\right]^2}_{p_j^1 = p_j^2} + \underbrace{\left[F_3(q_1,q_2) - F_2(q_2,f_2)\right]^2}_{p_j = p_j^2} \right\}}_{\varepsilon \text{ (error)}} \rightarrow 0$$



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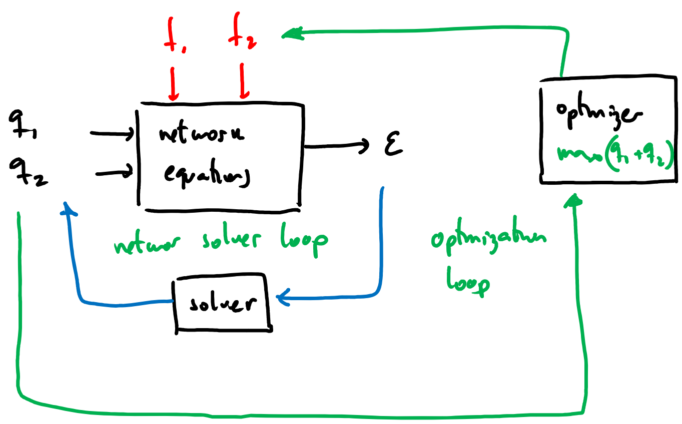
Setting up the optimization: optimizer «outside» the model



the two loops are solved sequentially

for each iteration of optimizer, the network solver must be converged

if the optimizer employs for a Newton method

$$\nabla(q_1,q_2) \quad \underbrace{\begin{matrix} \frac{\partial q_1}{\partial f_1} & \frac{\partial q_1}{\partial f_2} \\ \frac{\partial q_2}{\partial f_1} & \frac{\partial q_2}{\partial f_2} \end{matrix}}_{\text{not typically output by network solver}}$$

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Details on optimization setup

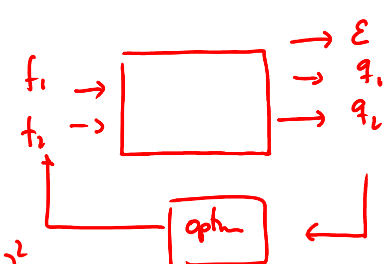
- Model + optimizer together

max $q_T = q_1 + q_2$

by changing f_1, f_2, q_1, q_2

subject to constraint: $\varepsilon = 0$

$$\left[F_1(q_1,f_1) - F_2(q_1,f_2)\right]^2 + \left[F_3(q_1,q_2) - F_2(q_2,f_1)\right]^2 = 0$$



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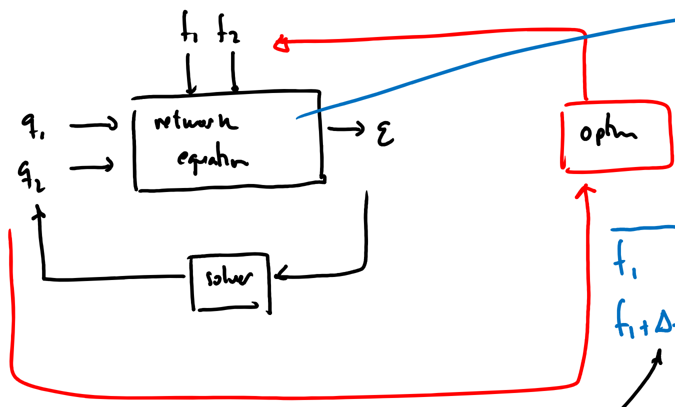
«Black-box» optimization (optimizer outside)



if black box, I don't have access to $\frac{\partial}{\partial f}$ (analytical eq)

one option is to estimate numerically the gradient (can be expensive for large number of variables)

f_1	q^1_{TOTAL}
$f_1 + \Delta f$	q^2_{TOTAL}

perturbation

$$\frac{\partial q_T}{\partial f_1} = \frac{q^2_{TOTAL} - q^1_{TOTAL}}{\Delta f}$$

derivative free: if Nelder-mead f_1^1 f_1^2 f_1^3

three function evaluations

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Effect of optimization formulation

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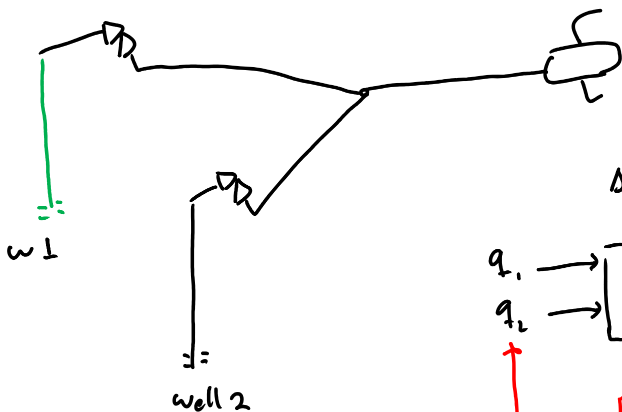
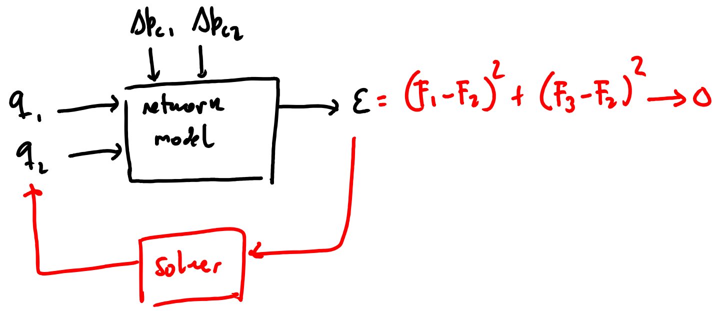
2. Two gas wells in a network – Optimization with DP choke



$p_j^1 = F_1(q_1, \Delta p_{c1})$

$p_j^2 = F_2(q_2, \Delta p_{c2})$

$p_j = F_3(q_1, q_2)$



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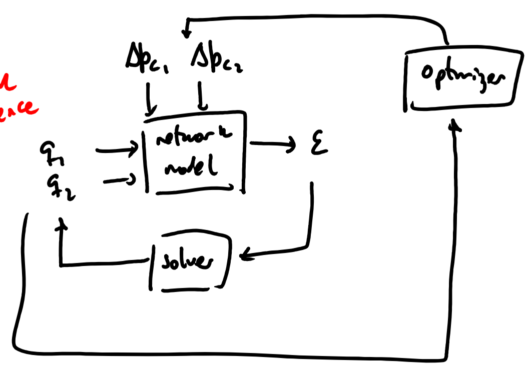
2. Two gas wells in a network – Optimization with gas rates

max $q_{Ttotal} = q_1 + q_2$

by changing Δp_{c1}, Δp_{c2}, q_1, q_2

subject to $\varepsilon = 0$ $\quad \underbrace{(F_1 - F_2)^2 + (F_3 - F_2)^2}_{\text{non-linear function}}$ network convergence

$q_1 \leq q_{gj\,max}$



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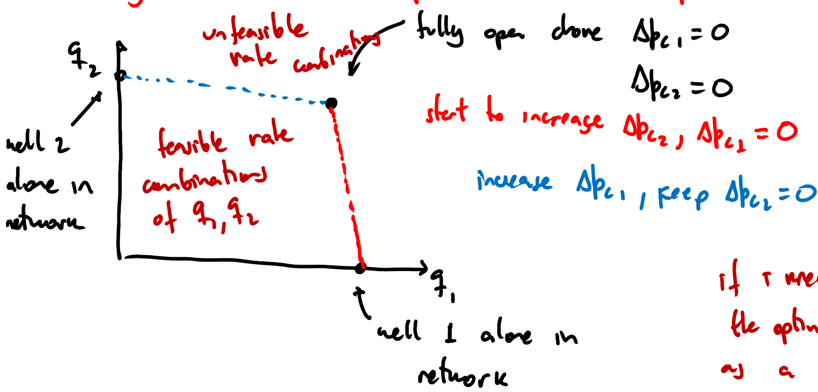
2. Two gas wells in a network - Differences when formulating the problem

Let's try to reformulate the problem as a linear problem



if I knew this area before hand, then the optimization can be re-formulated as a linear problem

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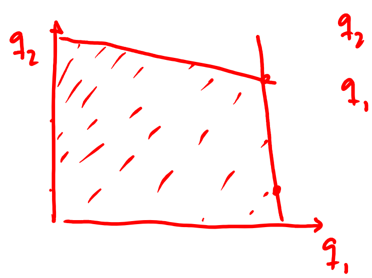
2. Two gas wells in a network - Differences when formulating the problem

max $q_1 + q_2 = q_T$ linear problem!

subject to $q_1 \leq q_{max}$

$q_2 \leq q_2^\circ - a \cdot q_1$

$q_1 \leq \underline{q_1^\circ - b\, q_2}$



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2. Two gas wells in a network - Differences when formulating the problem

```
#ESTIMATING FEASIBLE OPERATING REGION, qg1, qg2
qg1=[]
qg2=[]
dp2=0
DP=np.linspace(250,0,10)
for dp1 in DP:
    x=minimize(error,qg,args=(pR,CR,n,CT,S,Cpl,Cfl,psep,[dp1,dp2]),method='Nelder-Mead')
    qg1=np.append(qg1,x.x[0])
    qg2=np.append(qg2,x.x[1])
DP=np.linspace(0,250,10)
dp1=0
for dp2 in DP:
    x=minimize(error,qg,args=(pR,CR,n,CT,S,Cpl,Cfl,psep,[dp1,dp2]),method='Nelder-Mead')
    qg1=np.append(qg1,x.x[0])
    qg2=np.append(qg2,x.x[1])
plt.plot(qg1/1e06,qg2/1e06)
plt.xlabel('qg_w1 [1e6 Sm3/d]',fontsize=14)
plt.ylabel('qg_w2 [1e6 Sm3/d]',fontsize=14)
plt.xlim(0)
plt.ylim(0)
plt.show()
```

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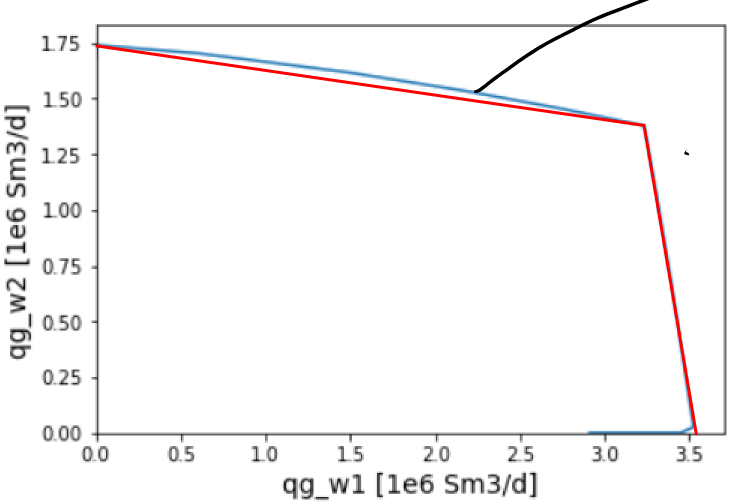
2. Two gas wells in a network - Differences when formulating the problem

deviation between linear approximation and real behavior:

$$\underbrace{q_2 \leq q_2^0 - a q_1 - b q_1^2}_{\text{this is non-linear !}}$$



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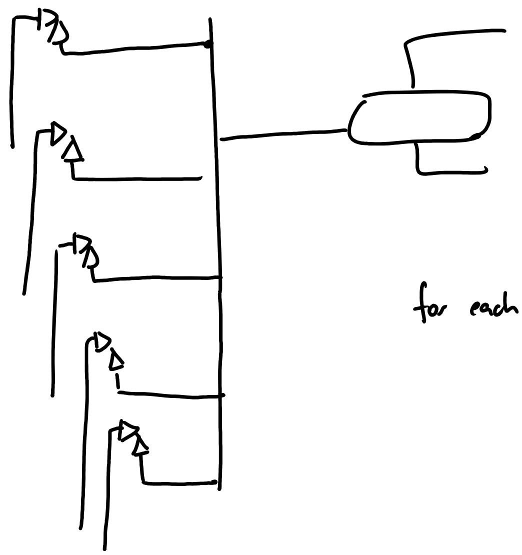
3. Well routing – class exercise



wells have different GOR, WC

find how much to produce from each well, to maximize total oil production and be below constraints

$q_{w\,max}$

$q_{g\,max}$

for each well $\underbrace{q_o^i = f(\Delta p_c^i)}_{\text{IPR, TPR, choke eq.}}$ → non linear function !

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3. Well routing – class exercise

one option

max $q_o^T = \sum_{i=1}^{5} q_o^i$ — $q_o^i = f(\Delta p_c^i)$ is non-linear !

by changing Δp_c^i for $i = 1 .. N$

subject to $\sum_{i=1}^{N} q_g^i \le q_{g\,max}$

$\sum_{i=1}^{N} q_w^i \le q_{w\,max}$

A different approach ... to make it linear

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3. Well routing – class exercise

max $\quad q_o = q_{\bar{o}_1} + q_{\bar{o}_2} + q_{\bar{o}_3} + q_{\bar{o}_4} + q_{\bar{o}_5}$

by changing $\quad q_{\bar{o}_1}, q_{\bar{o}_2}, q_{\bar{o}_3}, q_{\bar{o}_4}, q_{\bar{o}_5}$

subject to

$$\sum_{i=1}^{N} q_{\bar{g}}^i \le q_{\bar{g}\,max} \qquad q_{\bar{g}}^i = q_{\bar{o}}^i \cdot GOR^i$$

$$\sum_{i=1}^{N} q_{\bar{w}}^i \le q_{\bar{w}\,max} \qquad q_{\bar{w}}^i = q_{\bar{o}}^i \cdot \frac{wc^i}{(1-wc^i)}$$

$q_{\bar{o}_1} \le q_{\bar{o}_1,max}$ ← fully open choke $\left\{\right.$ either from model or from field test

$q_{\bar{o}_2} \le q_{\bar{o}_2,max} \qquad q_{\bar{o}_4} \le q_{\bar{o}_4,max}$

$q_{\bar{o}_3} \le q_{\bar{o}_3,max} \qquad q_{\bar{o}_5} \le q_{\bar{o}_5,max}$

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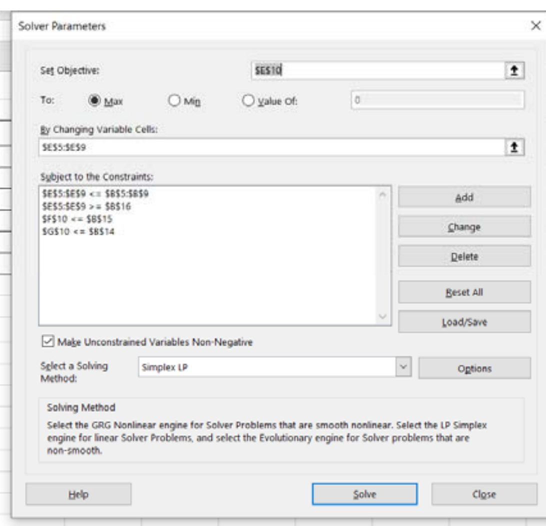
3. Well routing – class exercise

E10 =SUM(G5:G9)

	A	B	C	D	E	F	G
1	PRODUCTION OTIMIZATION						
2	5 Well Optimization Problem						
3	Well	q_{maxo}	WC	GOR	qo	qg	qw
4		Sm3/D	fraction	Sm3/m3	Sm3/D	Sm3/D	Sm3/D
5	1	636	0.20	142	635.6	90255.2	158.9
6	2	795	0.43	214	698.1966	149134.8	526.7097
7	3	477	0.31	267	50	13350	22.46377
8	4	636	0.47	356	50	17800	44.33962
9	5	318	0.10	249	50	12460	5.555556
10				qototal [Sm3/d]	1483.797	283000	757.9687
11							
12	Constraints Separator						
13	qo	No Limit	Sm³/d	Maximize oil production			
14	qw	795	Sm³/d				
15	qg	283.0E+3	Sm³/d				
16	qo min	50	Sm³/d				
17							
18							
19							
20							
21							



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Optimization types

- Parametric (static) – using a model
- **Dynamic (control)** – using a model, physical system, or a combination of both

https://en.wikipedia.org/wiki/Simulation-based_optimization

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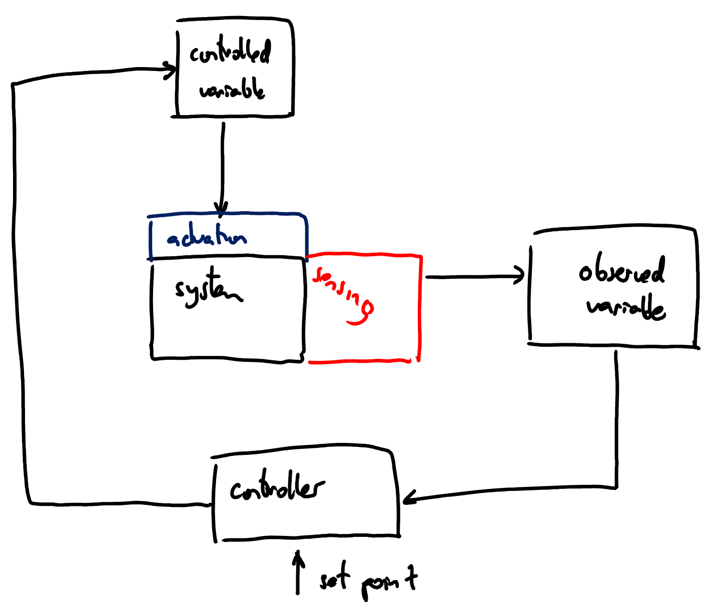
Dynamic optimization (control)



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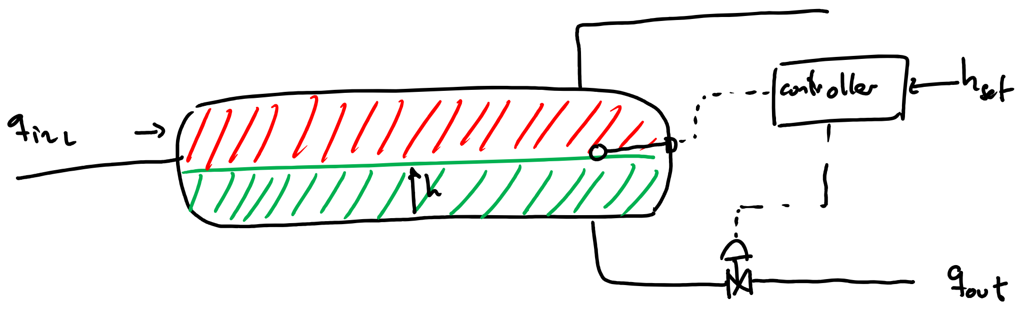
Dynamic optimization (control): gas-liquid separator



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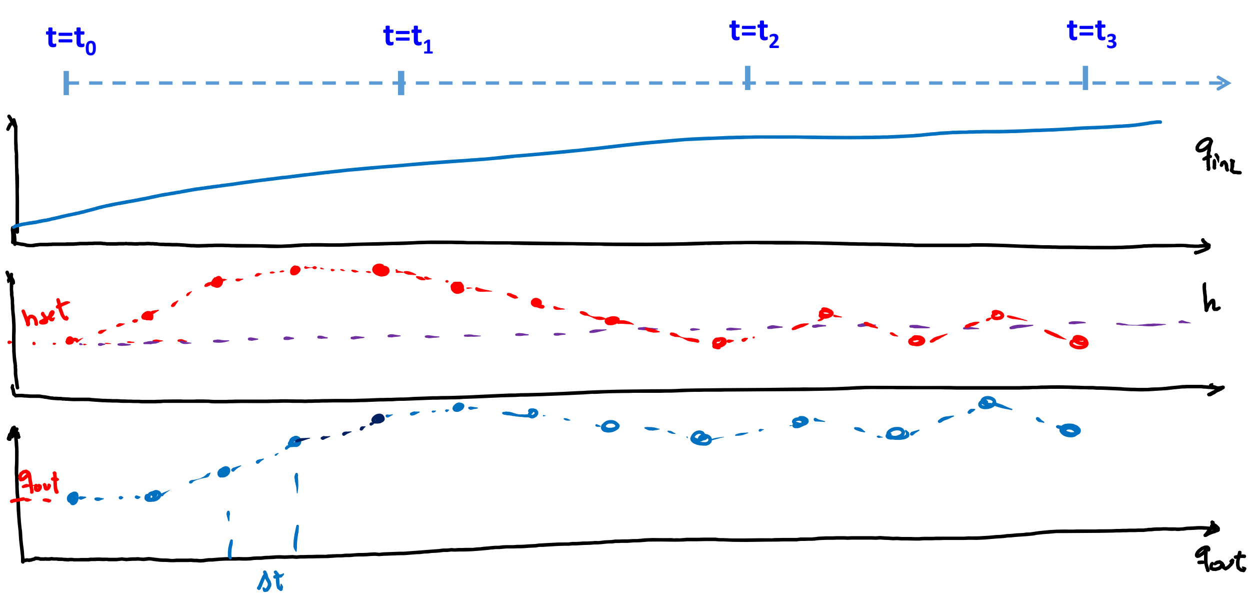

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Dynamic optimization (control)

to calculate $h(t)$ we need $\leadsto$ model (transient mode)

↳ measurement on physical system

but we can also apply control using a steady state model. for example in the gas lift case $q_o = f(q^1_{ginj}, q^2_{ginj})$

we evaluate the function in each time, depending on the value of q^1_{ginj} and q^2_{ginj}

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Dynamic optimization (control)

↑ check q_o^{*} $\rightarrow \boxed{\text{controller}} \rightarrow$ q^1_{ginj}, q^2_{ginj}

then on t_3, evaluate $q_o = f(\;,\;)$, then

$q_o^{**} \rightarrow \boxed{\text{controller}} \rightarrow q^1_{ginj}, q^2_{ginj}$

one approach to make the controller optimize is to drive $\frac{\partial q_o}{\partial q^1_{ginj}} = 0$, $\frac{\partial q_o}{\partial q^2_{ginj}} \to 0$

$$\frac{\partial q_o}{\partial q^1_{ginj}} = \frac{\partial q_o}{\partial q^2_{ginj}}$$

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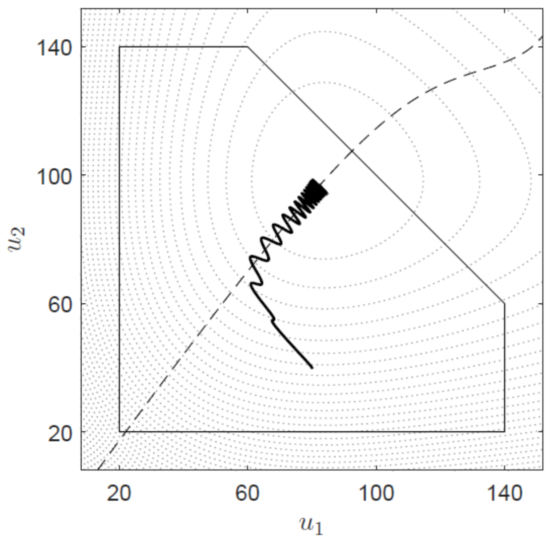
Dynamic optimization (control)



Practical extremum-seeking control for gas lifted oil production – Pavlov et al

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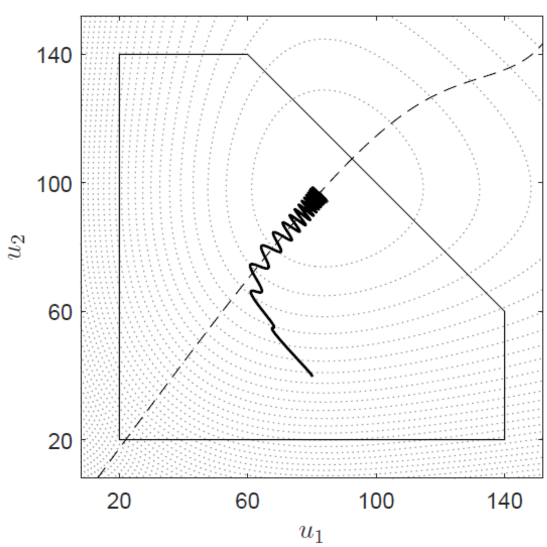
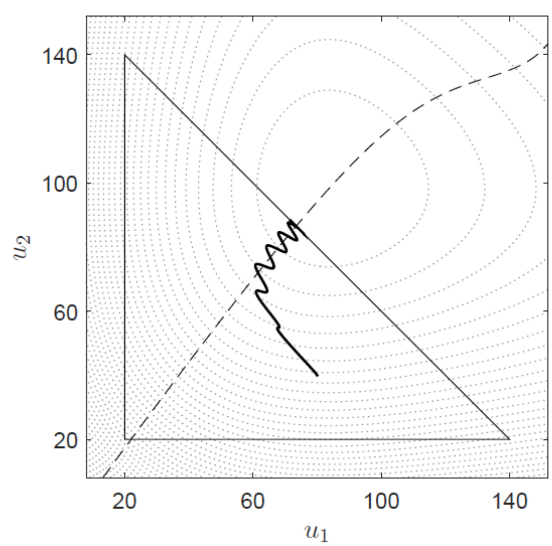
Dynamic optimization (control)





Practical extremum-seeking control for gas lifted oil production – Pavlov et al

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Limitations and pitfalls

- Model fidelity
- Is it actually possible to change the decision settings?:
  - Is the equipment/actuator functional and available?
  - Am I allowed to operate the control element?
  - Actuator response time

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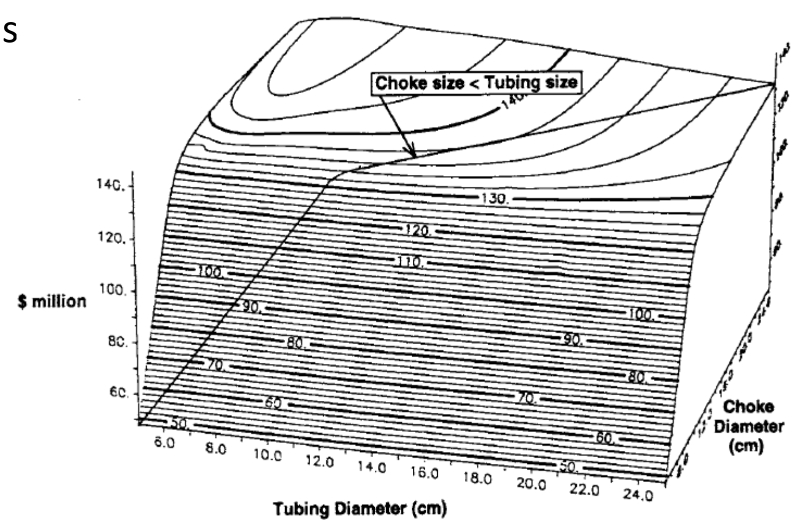
Limitations and pitfalls

- Flat peak of optimum- more efforts give less res



SPE-166027-MS Multivariate optimization of production systems optimization Carroll and Horne

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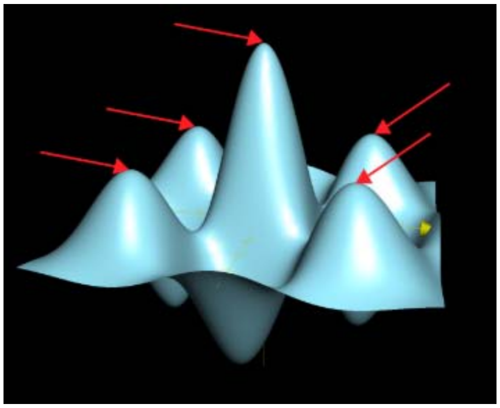
Limitations and pitfalls

- Local optima
- Starting point
- Running time
- Short term versus long term optimization



(Khan academy)

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Limitations and pitfalls

- Short term versus long term optimization

Maximize NPV
By changing $q_o(t)$

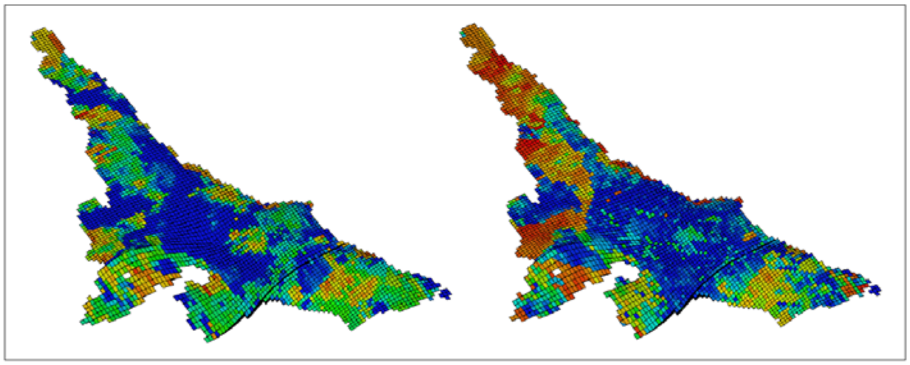

Figure 3: Permeability (left) and porosity (right) distributions of the south wing.

SPE-166027-MS Decision analysis for long term and short-term production optimization Applied to the Voador field, Agus Hasan

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- Short term versus long term optimization

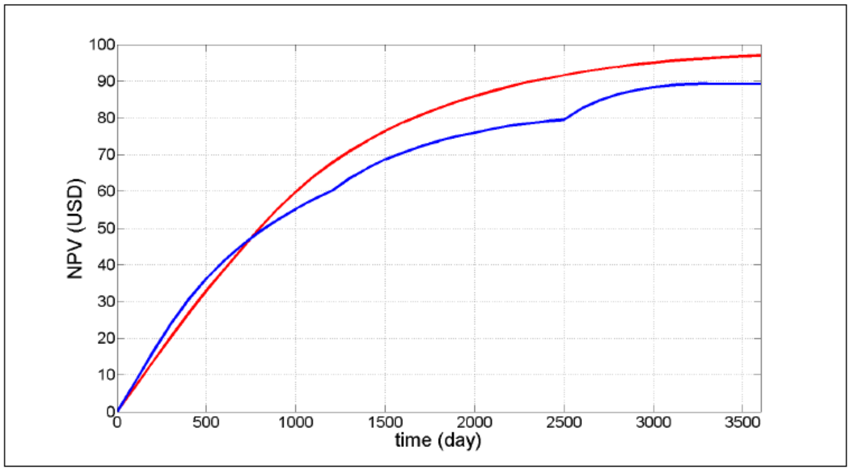

Figure 4: Normalized NPV of the long-term optimization (red) using adjoint-based optimization and short-term optimization (blue) using reactive control.

SPE-166027-MS Decision analysis for long term and short-term production optimization Applied to the Voador field, Agus Hasan

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- Short term versus long term optimization

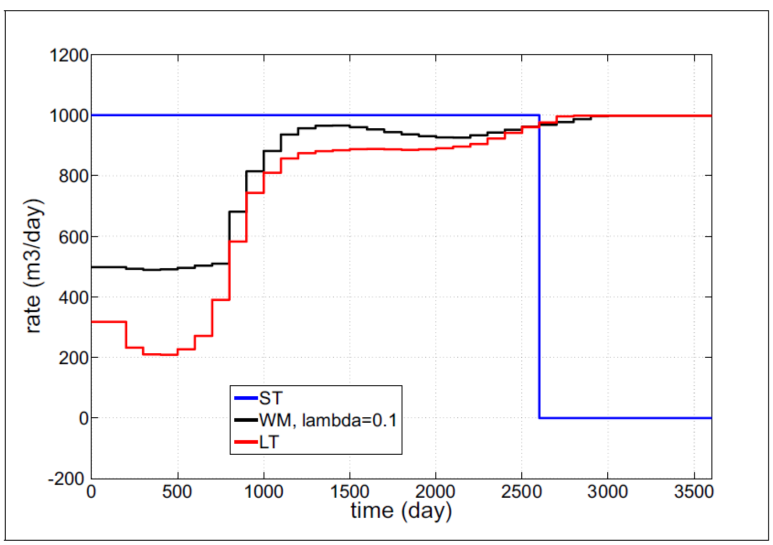

Figure 9: Oil rate from production well PROD3 using different strategies; reactive control (blue), adjoint-based optimization (red), and the weighted-sum method (black).

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Final advice:

- Look at the rest of the list first!
- Do we REALLY need to do optimization?
- Think carefully what is the main, most important, first order of magnitude problem
- Define objective, constraints and variables
- Determine relevance of constraints
- Is it realistic to modify optimization variables?
- Formulate your optimization in a smart way (choose the right variable)
- Study how your input affects your results

SLIDE 2

- Detect locations in the system with abnormally high-pressure loss and flow restrictions
- Verification of equipment design conditions vs actual operating conditions
- Identification and addressing fluid sources that have disadvantageous characteristics (e.g. high water cut, high H_2S content)
- Identify and correct system malfunctions and non-intended behavior
- Analyze and improve the logistics and planning of maintenance, replacement and installation of equipment or in the execution of field activities.
- Review the occurrence of failures and recognize patterns
- Calibration of instrumentation
- Identification of operational constraints (e.g. water handling capacity, power capacity)
- Observe and analyze the response of the system when changes are introduced
- Find control settings of equipment that give a production higher than current (or, preferably, that give maximum production possible)
- Identify Bottlenecks
- Identifying and monitoring Key Performance Indicators (KPIs)

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