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Mixed Integer Linear Programming Of Power Systems With Free Software

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Abstract

Computing tools applied in power systems are increasingly used to solve complex optimization problems. Power system operations research has become essential for graduate and final-year undergraduate students who want to improve their knowledge in this area. This study proposes a solution for a group of boilers and turbines to minimize operating costs using GUSEK software. The execution of the model allows us to obtain the optimal solution with the operational constraints involved and the possibility of improving with metaheuristic algorithms.

Keywords: GUSEK, optimization, MILP.

I. INTRODUCTION

Optimization methods used in power systems are increasingly essential to manage the grid efficiently. Computational improvements in software and hardware allow researchers to obtain better results in energy, given that the complexity of electrical systems requires advanced optimization methods for their solution. (El Kafazi et al., 2018; Lin et al., 2018).

Below is a summary of work using optimization models in power systems: In Quiggin et al., (2012), a microgrid is modeled using linear programming to reduce demand fluctuations and improve energy balance. In Sahraei Manjili et al., (2012), mixed integer linear programming was used to decrease the annual cost of using electric power using renewable energy components. Garcia & Bordons, (2013), used mixed integer linear programming (MILP) to solve the economic operation of a microgrid with renewable energy sources and energy storage from actual forecast data.

In Luna et al., (2017) defined a MILP strategy to minimize operating costs and promote self-consumption based on forecast data from a hybrid Microgrid in the laboratory of Aalborg University. In Guerrero Hernandez & de Arruda, (2021), a mixed integer nonlinear optimization model of a microgrid with hybrid storage was developed to analyze the benefits of the electricity tariff and maximize the income from photovoltaic generation. In Hernandez et al., (2022), defined MILP as a university microgrid to reduce consumption by importing energy and increasing the self-consumption of electrical energy from the set of photovoltaic panels.

Using computational tools in optimization problems is very important for the operations research course aimed at electrical and electronic engineering students. The objective is to encourage the formulation and solve relevant problems in their professional and academic life. During the Covid-19 pandemic, using freely accessible computational tools in practical university courses became important, moving the natural workplace, such as the laboratory, to a remote environment that implied challenges for teachers (Carlos Muyulema-Allaica et al., 2021). This study shows a classic steam generator and turbine model with operating restrictions that allow one to make the best decision, simulated in an accessible interface for Windows and GUSEK software.

II. METHODOLOGY

Determine the amount of steam produced and consumed in three boilers and three turbines. To minimize costs in the production and processing of steam, generating an amount of 4,000 kW-hr in the first month, 8,000 kW-hr in the second month, and 11,000 kW-hr in the third month of power.

Boiler costs and operating characteristics (Table 1).

Table 1. Generator operating costs

Steam Generator	**Average minimum steam Ton-hr**	**average maximum steam Ton-hr**	**Ton Cost. (US$)**
1	500	1000	100
2	300	900	80
3	400	800	60

Costs and operational characteristics of turbines (Table2).

Table 2. Turbine operating costs

Turbina	**Minimum steamTon-hr**	**Maximum steamTon-hr**	**Kwh * ton. steam**	**Cost processing a ton of steam (US)**
1	300	600	4	20
2	500	800	5	30
3	600	900	6	40

The three boilers are supposed to be connected to a steam head and distribute steam to the three turbines in figure 1.

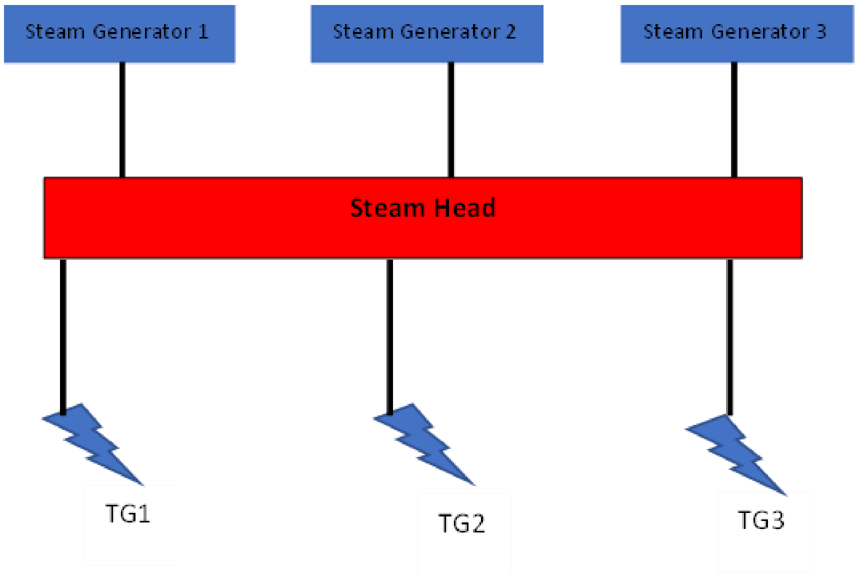


Figure 1. Steam Generation Schematic

Definition of variables.

$b_s t_m$ = Number of tons of steam produced in the boiler **s** (1,2,3) in time **m** (1,2,3).

$d_i t_m$ = Number of tons of steam consumed in the turbine **i**(1,2,3) in time **m**(1,2,3) **.**

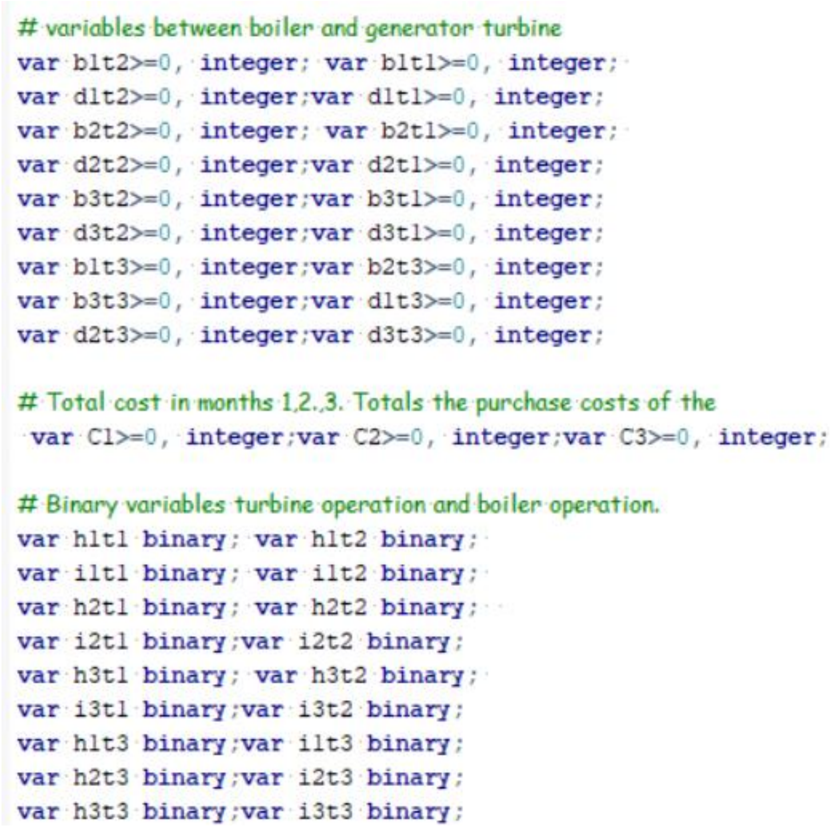
$$I_s t_m = \begin{cases} \mathbf{1} \text{ The boiler } \mathbf{s} \text{ does not operate within an operating interval in the month 1,2,3.} \\ 0 \text{ the boiler } \mathbf{s} \text{ operates within an operating interval in month 1,2,3} \end{cases} \quad (1)$$

$$h_i t_m = \begin{cases} \mathbf{1} \text{ the turbine } \mathbf{i} \text{ does not operate within an operating range in months 1,2,3} \\ \mathbf{0} \text{ the turbine } \mathbf{i} \text{ operates within an operating interval in the month 1,2,3} \end{cases}$$

(2)

C$_m$= cost every month 1,2,3.

Figure 2 shows the definition of inter and binary variables in GUSEK that are used for the steam generator problem.



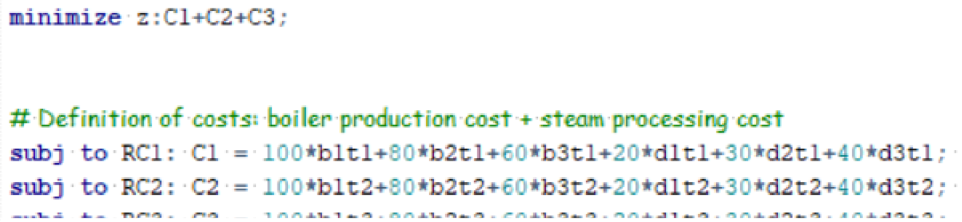
```
# variables between boiler and generator turbine
var b1t2>=0, integer; var b1t1>=0, integer;
var d1t2>=0, integer;var d1t1>=0, integer;
var b2t2>=0, integer; var b2t1>=0, integer;
var d2t2>=0, integer;var d2t1>=0, integer;
var b3t2>=0, integer;var b3t1>=0, integer;
var d3t2>=0, integer;var d3t1>=0, integer;
var b1t3>=0, integer;var b2t3>=0, integer;
var b3t3>=0, integer;var d1t3>=0, integer;
var d2t3>=0, integer;var d3t3>=0, integer;

# Total cost in months 1,2..3. Totals the purchase costs of the
 var C1>=0, integer;var C2>=0, integer;var C3>=0, integer;

# Binary variables turbine operation and boiler operation.
var h1t1 binary; var h1t2 binary;
var i1t1 binary; var i1t2 binary;
var h2t1 binary; var h2t2 binary;
var i2t1 binary;var i2t2 binary;
var h3t1 binary; var h3t2 binary;
var i3t1 binary;var i3t2 binary;
var h1t3 binary;var i1t3 binary;
var h2t3 binary;var i2t3 binary;
var h3t3 binary;var i3t3 binary;
```

Figure 2. Binary and integer variables

Objective function.

The objective function requires minimizing boiler vapors' production costs and the turbines' steam processing costs in months 1, month two, and 3 (Figure 3).

$$\text{Totalcost}_{123} = \text{Productioncost}_{123} + \text{Processingcost}_{123} \qquad (3)$$



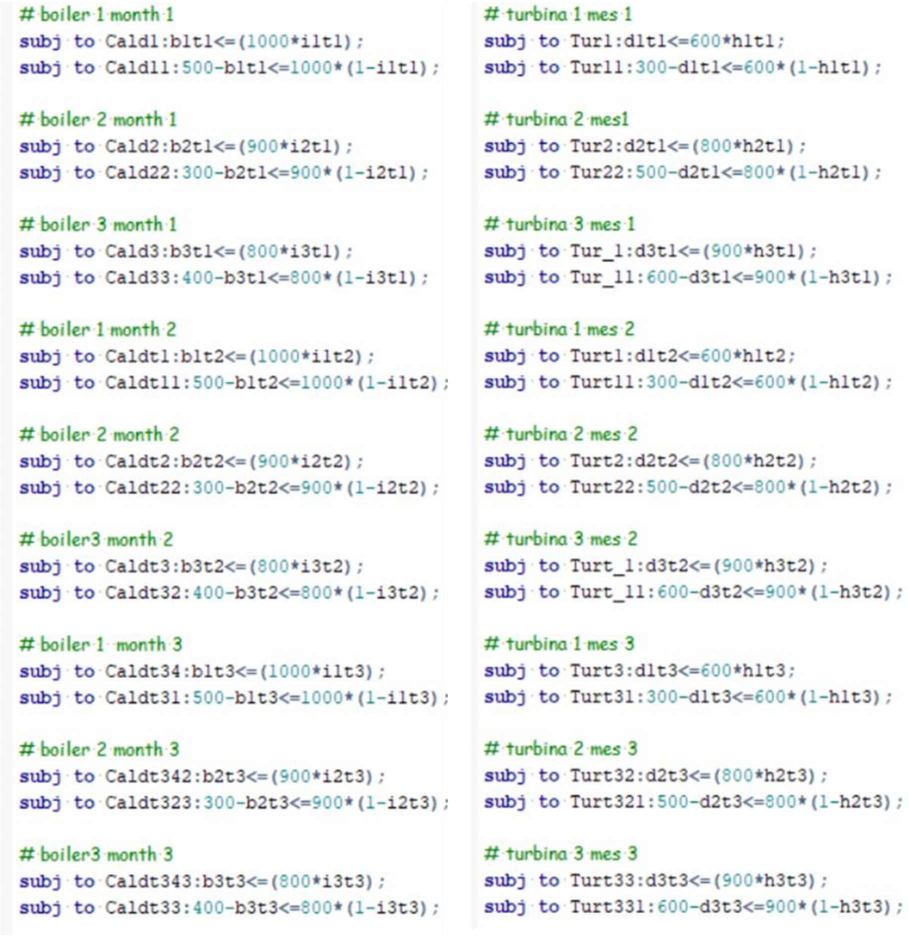
```
minimize z:C1+C2+C3;


# Definition of costs: boiler production cost + steam processing cost
subj to RC1: C1 = 100*b1t1+80*b2t1+60*b3t1+20*d1t1+30*d2t1+40*d3t1;
subj to RC2: C2 = 100*b1t2+80*b2t2+60*b3t2+20*d1t2+30*d2t2+40*d3t2;
```

Figure 3. Objetive function equation

Restrictions.

The restrictions are conditioned to the problem of the steam generator and turbines (Figure 4).

- A boiler may or may not work. If the boiler works, it must operate within the specified capacity range.
- A turbine can operate or not. If it works, it must operate within the specified range.

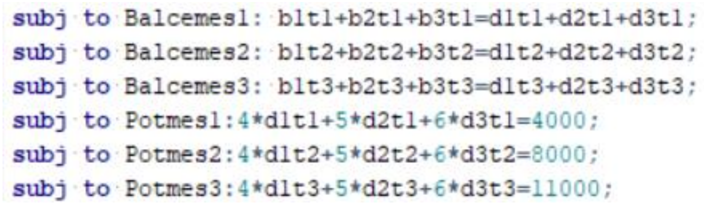


```
# boiler 1 month 1
subj to Cald1:b1t1<=(1000*i1t1);
subj to Cald11:500-b1t1<=1000*(1-i1t1);

# boiler 2 month 1
subj to Cald2:b2t1<=(900*i2t1);
subj to Cald22:300-b2t1<=900*(1-i2t1);

# boiler 3 month 1
subj to Cald3:b3t1<=(800*i3t1);
subj to Cald33:400-b3t1<=800*(1-i3t1);

# boiler 1 month 2
subj to Caldt1:b1t2<=(1000*i1t2);
subj to Caldt11:500-b1t2<=1000*(1-i1t2);

# boiler 2 month 2
subj to Caldt2:b2t2<=(900*i2t2);
subj to Caldt22:300-b2t2<=900*(1-i2t2);

# boiler3 month 2
subj to Caldt3:b3t2<=(800*i3t2);
subj to Caldt32:400-b3t2<=800*(1-i3t2);

# boiler 1  month 3
subj to Caldt34:b1t3<=(1000*i1t3);
subj to Caldt31:500-b1t3<=1000*(1-i1t3);

# boiler 2 month 3
subj to Caldt342:b2t3<=(900*i2t3);
subj to Caldt323:300-b2t3<=900*(1-i2t3);

# boiler3 month 3
subj to Caldt343:b3t3<=(800*i3t3);
subj to Caldt33:400-b3t3<=800*(1-i3t3);
```

```
# turbina 1 mes 1
subj to Tur1:d1t1<=600*h1t1;
subj to Tur11:300-d1t1<=600*(1-h1t1);

# turbina 2 mes1
subj to Tur2:d2t1<=(800*h2t1);
subj to Tur22:500-d2t1<=800*(1-h2t1);

# turbina 3 mes 1
subj to Tur_1:d3t1<=(900*h3t1);
subj to Tur_11:600-d3t1<=900*(1-h3t1);

# turbina 1 mes 2
subj to Turt1:d1t2<=600*h1t2;
subj to Turt11:300-d1t2<=600*(1-h1t2);

# turbina 2 mes 2
subj to Turt2:d2t2<=(800*h2t2);
subj to Turt22:500-d2t2<=800*(1-h2t2);

# turbina 3 mes 2
subj to Turt_1:d3t2<=(900*h3t2);
subj to Turt_11:600-d3t2<=900*(1-h3t2);

# turbina 1 mes 3
subj to Turt3:d1t3<=600*h1t3;
subj to Turt31:300-d1t3<=600*(1-h1t3);

# turbina 2 mes 3
subj to Turt32:d2t3<=(800*h2t3);
subj to Turt321:500-d2t3<=800*(1-h2t3);

# turbina 3 mes 3
subj to Turt33:d3t3<=(900*h3t3);
subj to Turt331:600-d3t3<=900*(1-h3t3);
```

Figure 4. Restrictions in Gusek

Figure 5 shows the operating balance equations for boilers and turbines under the constraints given in Table 1 and Table 2.



```
subj to Balcemes1: b1t1+b2t1+b3t1=d1t1+d2t1+d3t1;
subj to Balcemes2: b1t2+b2t2+b3t2=d1t2+d2t2+d3t2;
subj to Balcemes3: b1t3+b2t3+b3t3=d1t3+d2t3+d3t3;
subj to Potmes1:4*d1t1+5*d2t1+6*d3t1=4000;
subj to Potmes2:4*d1t2+5*d2t2+6*d3t2=8000;
subj to Potmes3:4*d1t3+5*d2t3+6*d3t3=11000;
```

Figure 5. Balance and power restrictions

III. SIMULATION AND DISCUSSION OF THE RESULT

With GUSEK, the minimum cost of the target function is US $ 451,200. Table 3 shows the flow of steam between boilers and turbines.

Variables	Month 1	Month 2	Month 3
Boiler 1	0	0	500
Boiler 2	0	620	800
Boiler 3	800	800	800
Turbine 1	0	0	400
Turbine 2	800	520	800
Turbine 3	0	900	900
Cost (US$)	**72000**	**149200**	**230000**

Figure 6 shows the dynamics of boilers and turbines. The proposed binary constraints aim to activate their operation in a specific month.

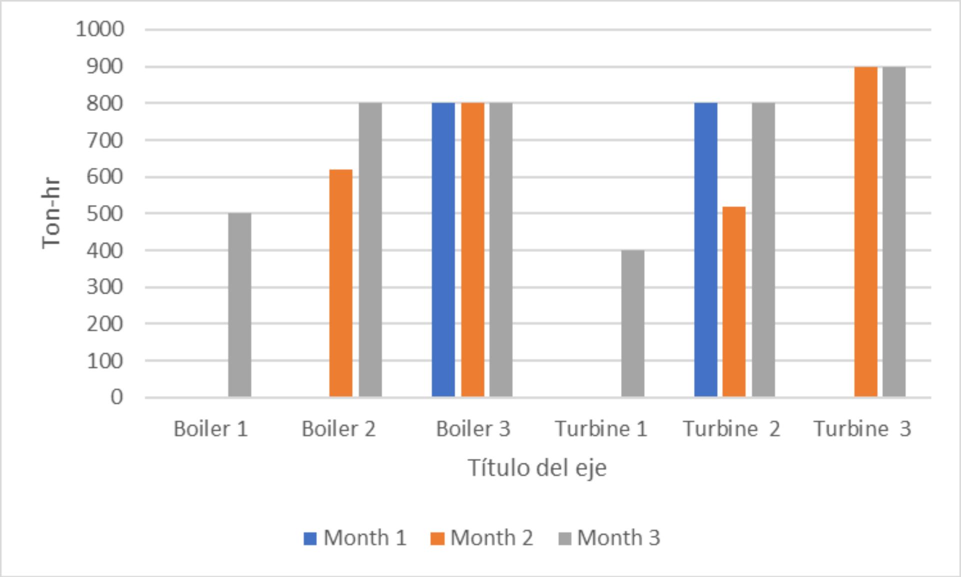


Figure 6. Dynamics of operation of boilers and generators

IV. CONCLUSIONS

This study developed a power distribution model in a group of boilers and turbines considering the technical constraints, also their production capacity. The model identified the constraints and simulated their behavior by processing the data with the Gusek tool, establishing an optimal solution. The model indicates that the minimum cost is US $ 451,200, considering that the boiler and turbine can be activated monthly. In a future study, metaheuristic algorithms can be considered to compare performance with current algorithms and improve the quality of the solution.

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