Self Unit Commitment of Combined-Cycle Units with Real Operational Constraints

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STRUCTURE

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INTRODUCTION

Combined Cycle Gas Turbine (CCGT) plants are one of the most common power technologies in the world due to their high efficiency and the high level of flexibility to support the integration of renewable energy resources. Hence, it is necessary to represent the operational elements of CCGTs in detail in a power system in order to simulate the correct output available in a specific period by the Independent System Operators (ISO) to meet demand and avoid critical damages in these plants.

Therefore, it is important to represent the intricate operating conditions of a CCGT in an optimization model in order to improve the CCGT's performance and meet technical operating constraints such as minimum heat requirements for steam to prevent equipment failures.

This work proposes a type of self-unit commitment (SEUC) model formulated as a Mixed Integer Programming (MIP) problem to overcome these shortcomings and to represent the detailed and realistic operating conditions of a CCGT plant given a specific dispatch.

Erosion on the blades as found

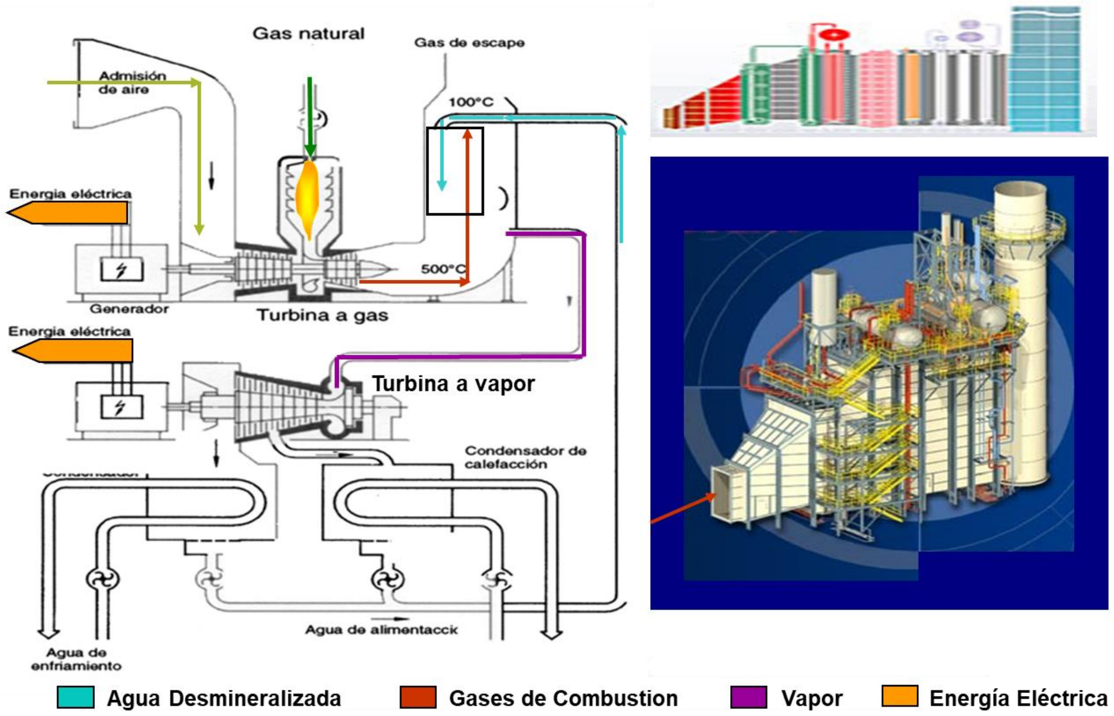
Erosion on the blades as found

Overview of gland sealing area

Close up of steam cuts / erosion

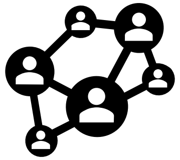
WHAT IS A COMBINE-CYCLE GAS UNIT

It is a power cycle that is based on the coupling of two different cycles, one of a steam turbine (Rankine cycle) and the other of a gas turbine (Brayton cycle). The heat not used by one of the cycles is used as a heat source for the other. In this way, the hot exhaust gases from the gas turbine cycle deliver the energy necessary for the operation of the coupled steam cycle. This configuration allows a very efficient use of fuel.

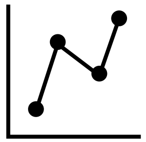


WAYS OF DISPATCH

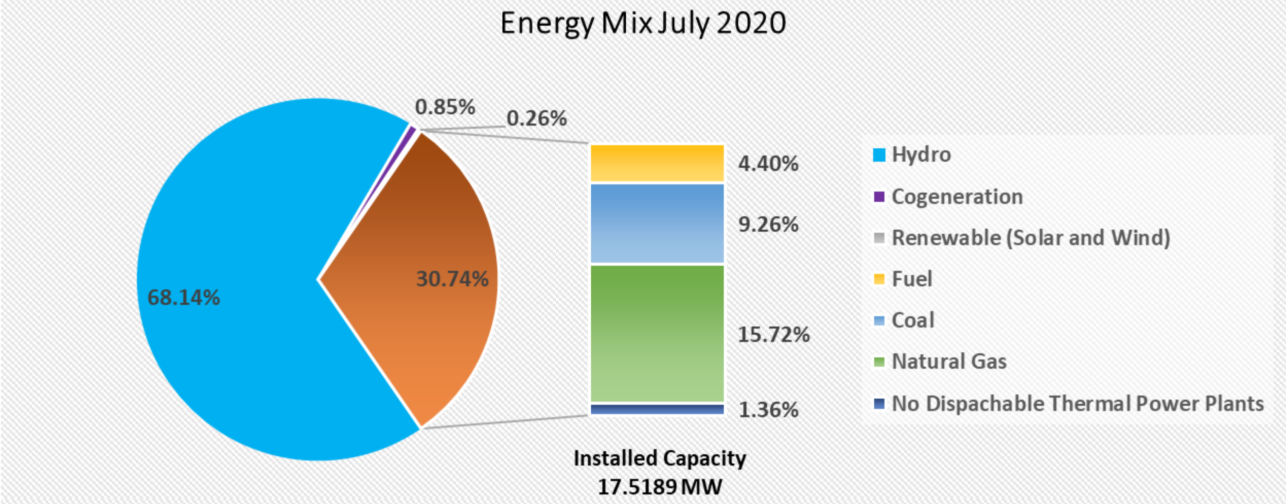
- Necessity of organize 3 basic functions of the industry
  - The instantaneous equilibrium between the supply and the demand
  - Network congestion management
  - Trade of electricity in the short term

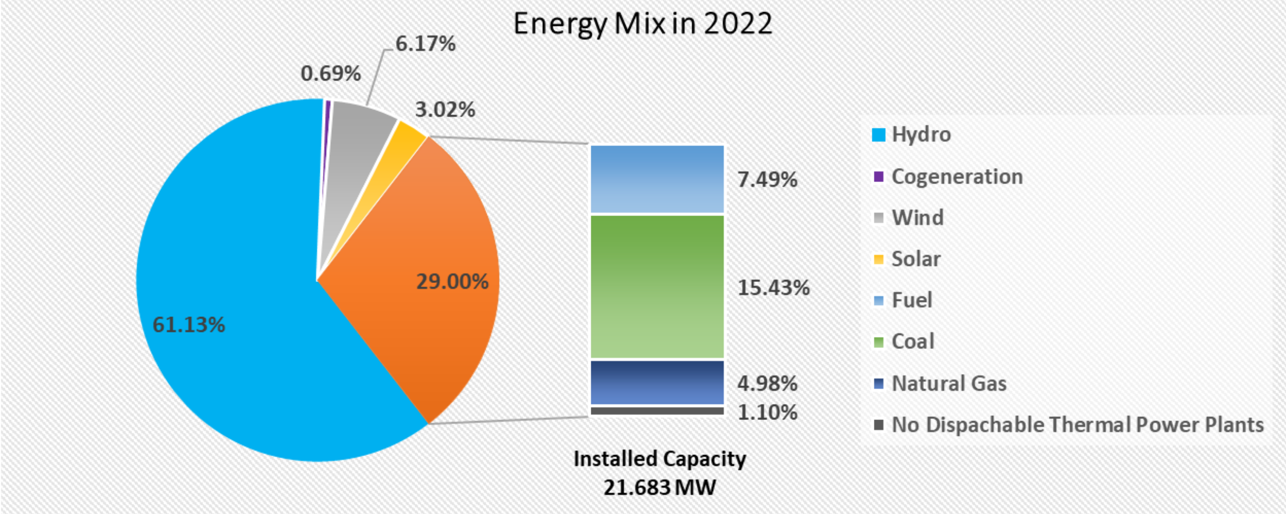


- Option:
  - Decentralize dispatch (Bilateral Model)
  - Centralize dispatch (Pool Model)
    - Tight pool or loose pool



COLOMBIAN ENERGY MARKET





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COLOMBIAN ENERGY MARKET

Electric system planning and operation process

Maintenance Plan
Utilities and generation companies report to ISO the maintenance plan for the next week

Unit Commitment
The ISO solve the UC problem

Day Ahead Dispatch
Generators have the commitment deliver an amount of energy for each hour for the operation day

The Operation Day
The ISO can reajust the dispatch to guarantee the reability

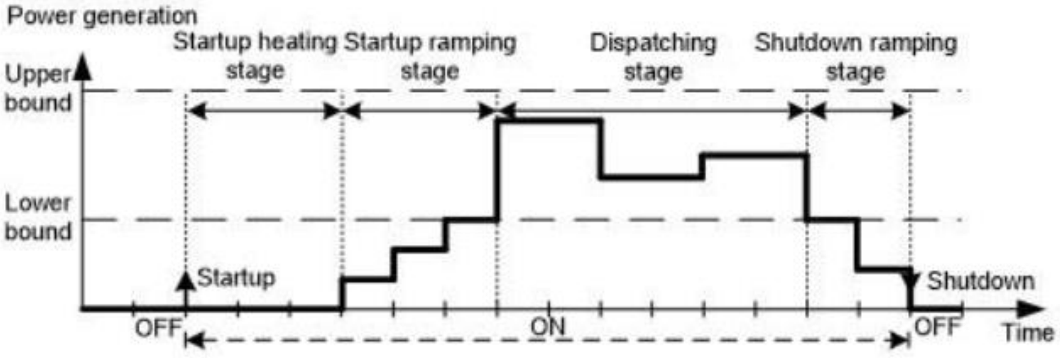
TYPICAL UNIT COMMITMENT

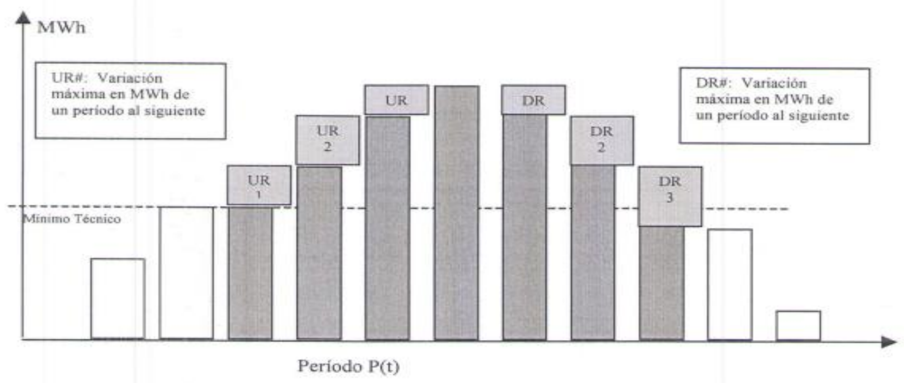
Fuente: CND | Agua | Líquidos | Carbón | Gas | Sol | Marginal

planta	p_estimado	Total MWh	h1	h2	h3	h4	h5	h6	h7	h8	h9	h10	h11	h12	h13	h14	h15	h16	h17	h18	h19	h20	h21	h22	h23	h24
Costo Margina		85	82	82	82	82	82	82	82	82	82	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
No Despachada	DORADA1 ; CTGEMG1 ; CTGEMG2 ; TEMCALI ; CTGEMG3 ; TCENTRO1 ; MERILEC1 ; TYOPAL1 ; BARRANQ … PAEMG4 ; ZIPAEMG5 ; ZIPAEMG2 ; TASAJERO2 ; PAIPA1 ; PAIPA2 ; PAIPA3 ; SALTO II																									
TSIERRA	847	3254	136	136	136	136	136	136	136	136	136	136	136	136	134	134	134	134	134	136	136	136	136	136	136	136
TERMONORTE	745	644	62	62	26	0	0	0	0	0	0	0	0	0	0	0	0	17	43	62	62	62	62	62	62	62
BARRANQ4	673.604	174	33	33	33	33	33	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TYOPAL2	606	158	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	22	22	22	22	22	22	22
TCANDEL1	622.809	325	0	0	0	65	65	65	65	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TCANDEL2	634.751	325	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	65	65	65	65	65	0	0	0
FLORES1	515	975	0	0	0	0	0	0	0	20	30	30	50	65	65	65	65	65	65	65	65	65	65	65	65	65
TEBSA	448.501	10312	470	464	405	312	312	332	591	589	332	312	312	312	312	312	312	335	672	620	337	481	555	524	583	526
GUAJIR21	291	2650	145	145	145	115	72	72	129	129	72	72	72	72	72	72	72	72	129	145	123	145	145	145	145	145
ZIPAEMG3	205	580	0	0	0	0	8	14	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
TASAJER1	162	3960	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165
PAIPA4	138	848	0	0	0	0	0	0	0	48	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
MIEL1	90	1584	330	264	198	132	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
SALVAJINA	90	2365	60	60	60	60	60	60	60	60	60	95	95	95	95	95	95	95	95	125	220	220	220	125	95	60
CALIMA1	89	96	0	0	0	0	0	0	0	48	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GUAVIO	87	6040	135	110	105	120	120	115	120	225	280	300	310	295	325	315	290	310	355	365	275	280	310	295	350	335
GUATRON	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLAYAS	87	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55	0	0	0	0
PORCE2	87	1037	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	246	397	394	0	0	0
ESMERALDA	84	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	15	15	0	0	0
CUCUANA	83	168	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56	56	56	0	0	0
BETANIA	82	4712	60	60	60	60	60	60	60	60	60	60	87	403	463	433	378	198	60	60	489	489	489	443	60	60
LATASAJERA	82	3337	51	0	0	0	4	0	0	0	0	28	306	306	306	306	306	306	0	0	306	306	306	306	194	0
SANFRANCISC(	82	270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	90	90	0	0	0
ESCUELAMINA	82	1320	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
ELQUIMBO	82	9230	400	400	400	400	400	400	400	400	400	400	395	315	315	315	315	375	400	400	400	400	400	400	400	400
SANMIGUEL	82	1056	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
SOGAMOSO	82	19656	819	819	819	819	819	819	819	819	819	819	819	819	819	819	819	819	819	819	819	819	819	819	819	819
TYOPAL3	82	1192	50	50	50	50	50	50	50	50	50	49	49	49	49	49	49	49	49	50	50	50	50	50	50	50
TYOPAL4	82	1200	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
C_LLERAS	82	1680	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
CHIVOR	82	18905	814	814	814	814	814	814	814	814	814	814	814	814	814	814	814	814	814	814	600	611	600	814	814	814
JAGUAS	82	2040	0	0	0	0	0	0	0	0	0	170	170	170	170	170	170	170	0	0	170	170	170	170	170	0
PRADO	82	1224	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
GUATAPE	82	13440	560	560	560	560	560	560	560	560	560	560	560	560	560	560	560	560	560	560	560	560	560	560	560	560
ALBAN	82	4733	153	153	153	153	193	193	193	193	193	193	193	193	193	193	193	193	193	193	280	280	280	193	193	193
SANCARLOS	82	25521	1085	1053	1043	1061	1085	1085	857	892	1085	1085	1085	1085	1085	1085	1085	1085	1085	1085	1085	1085	1085	1085	1085	1085
PORCE3	82	11751	175	125	125	125	175	150	0	0	506	700	700	700	700	700	700	700	684	595	700	700	700	700	700	691
URRA	82	6498	227	227	227	227	227	227	227	297	297	297	297	297	297	297	297	297	297	297	297	297	297	297	227	227
RN_SELPASO	74	289	0	0	0	0	0	0	4	21	25	22	30	41	46	44	30	15	8	3	0	0	0	0	0	0
MENR	74	19333	815	810	809	812	812	813	813	813	823	814	821	836	841	854	848	843	831	832	832	828	715	707	704	707

THERMAL POWER PLANT CONSTRAINTS

Operation Stages





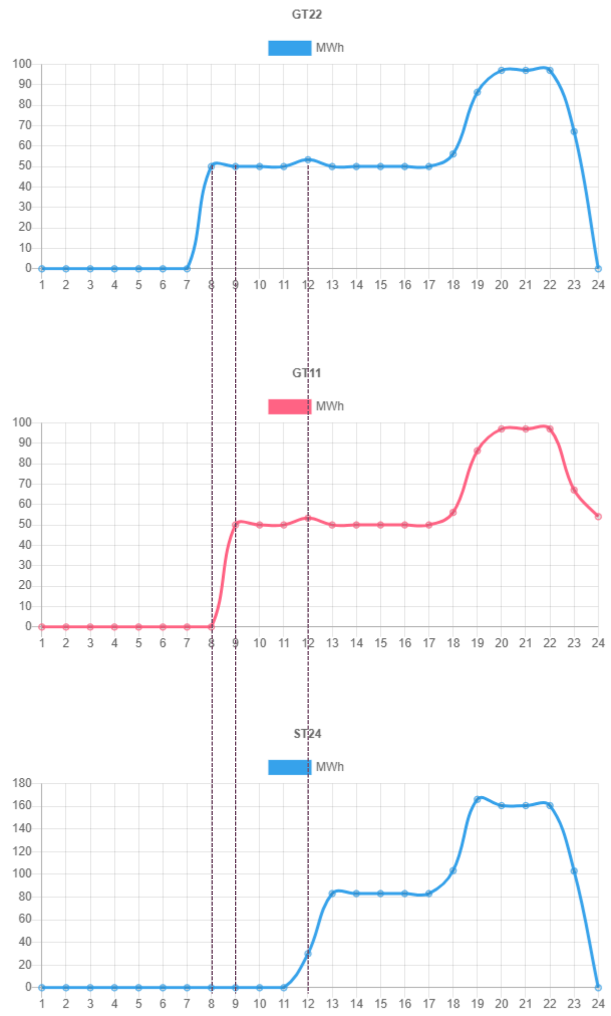
Basic Constraints

- ✓ Minimum up/down time
- ✓ Startup ramp (Model 1)
- ✓ Shut down ramp (Model 1)
- ✓ Up/Down ramp (Model 2 or 3)
- ✓ Additional fires
- ✓ Auxiliary consumption

Model 3: $a * P(t) - b * P(t-1) <= UR$

CCGT OPERATIONAL CONSTRAINTS

1. Minimum number of combustion units necessary to have a coupled operation in combined cycle with steam turbines.
2. Minimum startup hours required for the gas turbines to produce the steam needed for the steam turbines in the right qualities.
3. Differentiate between a hot and cold startup for the steam turbines.
4. Load distribution between combustion turbines that is necessary to guarantee a steam production given to each steam turbine in the same conditions and prevent temperature deltas in these units produced when the load between the gas turbine are not the same.



PROBLEM DESCRIPTION

- Colombian ISO does not dispose of a faithful technical representation of the corresponding CCGT plants.
- It is important to represent the intricate operating conditions of a CCGT to improve the CCGT's performance and meet technical operating constraints such as minimum heat requirements for steam to prevent equipment failures.
- Technical constraints are not commonly represented correctly with heuristic approximation models that are being used to operate the plant currently.
- Deviation and penalties due to the impossibility to attend the unit commitment plan.

Fecha de aplicación: Operación Diciembre 15 de 2007
Aprobado según acuerdo CNO 531 (Ver acuerdo)

Fecha de estudio : **2020-08-19**

PER	DES	AGC	SEG		220 KV							110 KV						GEN	DES	DES	GT's		ST	DGT		INF	
	ECO		220	110	CS	CC	ST	SEG	INF	TOT	FLAG	CS	CC	SEG	INF	TOT	FLAG		SEG	DEF	220	110		220	110	DES	RMP
17	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0				
18	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
19	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
20	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
21	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
22	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
23	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
24	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
01	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
02	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
03	0		0	0	0	0	[illegible]	[illegible]	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
04	0		0	0	0	0	[illegible]	[illegible]	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
05	0		0	0	0	0	[illegible]	[illegible]	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
06	0		0	0	0	[illegible]	[illegible]	[illegible]	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
07	0		0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
08	0		0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
09	0		0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
10	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
11	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
12	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
13	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
14	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
15	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
16	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0		
17	0		0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	50	0	1	0	0	1		50
18	0		1	1	0	0	1	40	0	40		0	1	80	0	80		113	73	204	0	1	1	0	0		131
19	0		1	1	0	0	1	40	0	40		0	1	80	0	80		113	73	351	1	2	1	1	1	161	117
20	800		5	2	0	3	2	303	0	303		0	2	100	0	100		392	800	800	3	2	2	2	0		
21	800		5	2	0	3	2	303	0	303		0	2	100	0	100		392	800	800	3	2	2	0	0		
22	800		5	2	0	3	2	303	0	303		0	2	100	0	100		392	800	800	3	2	2	0	0		
23	210		1	2	0	0	1	61	0	61		0	2	100	0	100		153	210	417	3	2	2	0	0	182	25
24	210		1	2	0	0	1	61	0	61		0	2	100	0	100		153	210	392	3	2	2	0	0	182	

Technical constraints are not represented correctly!

CASE STUDIES

CCGT Parameters

Variable	Value	Unit
$\overline{GCC}$	800	MW
$\underline{GCC}$	210	MW
PAF	15	MW
$AUXCC$	5	MW
$AUXGT$	0.45	MW
$AUXST$	2	MW
RD/RU	335	MWh
PCC	120	$\$/MWh$
PBC	500	$\$/MWh$
CSC	15000	$
MUG	2	p.u.
STF	0.613	p.u.
NC	5	p.u.
NS	2	p.u.
$t1$	t <= 16	Hours
$t2$	16 < t <= 30	Hours
$t3$	t > 30	Hours
KGC	3	Hours

Combustion Turbines

Variable	Value	Units
$\overline{G}$	100	MW
$\underline{G}$	50	MW
TC	5	MW/min
TD	5	MW/min

Steam Turbines

Variable	Value	Units
$\overline{G}$	170	MW
$\underline{G}$	80	MW
$GSTH$	80	MW
$GSTC$	30	MW

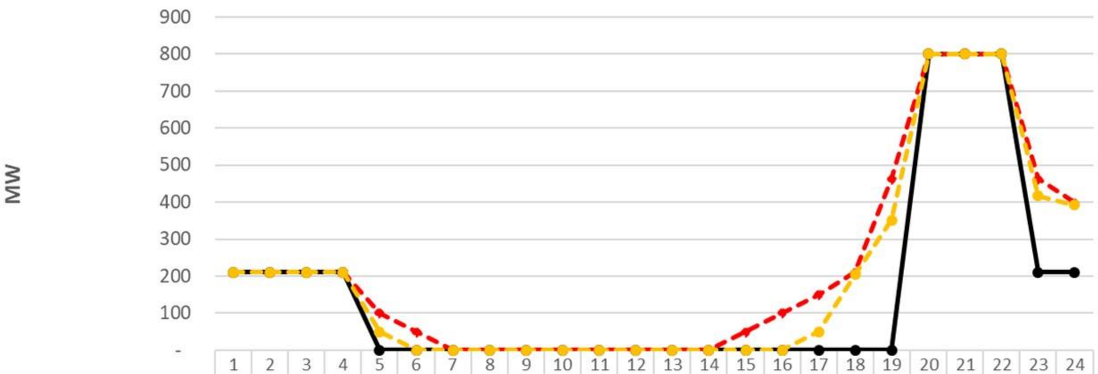
Startup and Shut Down Ramps

Hour	H-Startup	W-Startup	C-Startup	Shutdown
H1	50	50	50	210
H2	100	100	100	100
H3	150	100	100	50
H4	210	150	100	0
H5	0	210	150	0
H6	0	0	210	0

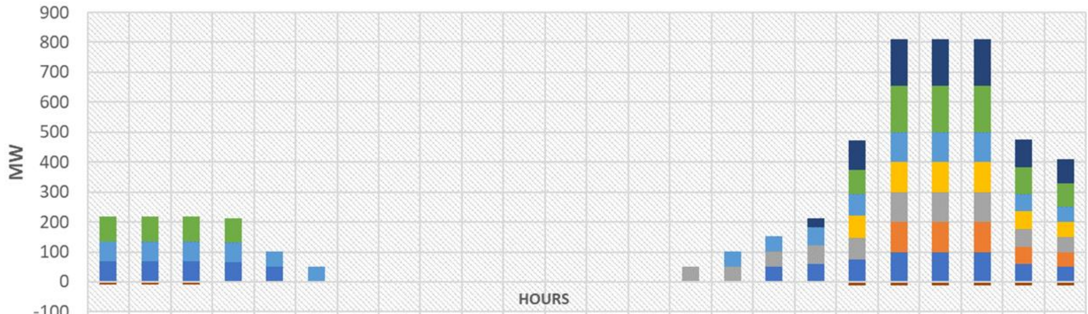
Unit	ton/off (Hours)	$Gt0$ (MW)
GT1	8	67
GT2	0	0
GT3	0	0
GT4	0	0
GT5	8	67
ST1	8	83
ST2	0	0

- The model decides to do a shutdown ramp in period 5, keeping the CCGT offline until period 15, where the model decides to do hot startup ramp.
- It is important to highlight that the model decides to ramp up in period 19 to reach the maximum capacity of the CCGT from period 20 to 22.

CASE 1



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
LOAD	210	210	210	210	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	800	800	800	210	210
GCCT OPM	210	210	210	210	100	50	-	-	-	-	-	-	-	-	50	100	150	210	463	800	800	800	463	399
HEURISTIC MODEL	210	210	210	210	50	-	-	-	-	-	-	-	-	-	-	-	50	204	351	800	800	800	417	392

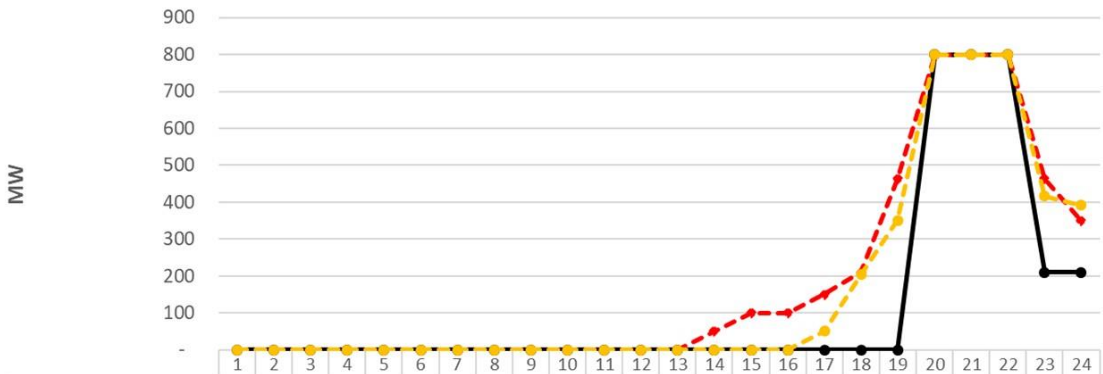


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
ST2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30.0	100.	155.	155.	155.	90.1	80.0
ST1	82.8	82.8	82.8	80.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	80.0	155.	155.	155.	90.1	80.0
GT5	67.5	67.5	67.5	66.0	50.4	50.4	-	-	-	-	-	-	-	-	-	50.4	50.4	61.1	73.4	100.	100.	100.	58.8	50.0
GT4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	73.4	100.	100.	100.	58.8	50.0
GT3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	50.4	50.4	50.4	61.1	73.4	100.	100.	100.	58.8	50.0
GT2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.	100.	100.	58.8	50.0
GT1	67.5	67.5	67.5	66.0	50.4	-	-	-	-	-	-	-	-	-	-	-	50.4	61.1	73.4	100.	100.	100.	58.8	50.0
AUX	-7.90	-7.90	-7.90	-2.90	-0.90	-0.45	-	-	-	-	-	-	-	-	-0.45	-0.90	-1.35	-3.35	-10.8	-11.2	-11.2	-11.2	-11.2	-11.2

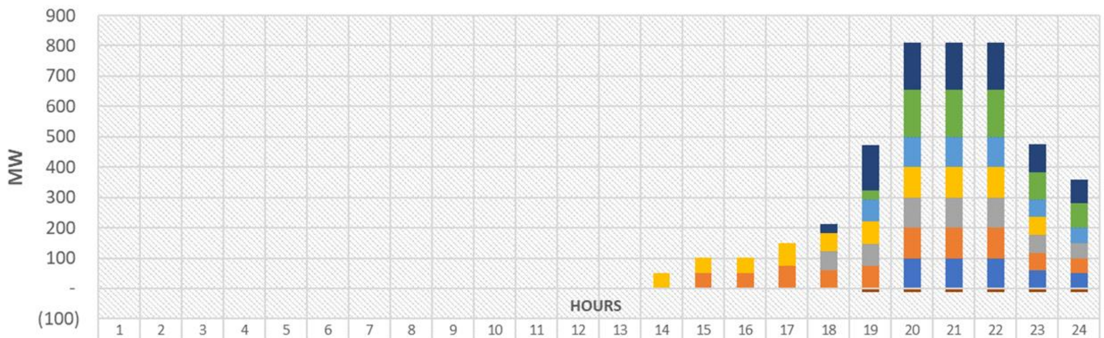
CASE 2

Unit	ton/off (Hours)	$Gt0$ (MW)
GT1	8	0
GT2	8	0
GT3	8	0
GT4	8	0
GT5	8	0
ST1	8	0
ST2	8	0

- It can be observed that to reach the initial dispatch L, a warm startup from periods 14 to 18 is required.
- an increased ramp is necessary in period 19 to deliver the maximum capacity in periods 20 to 22.
- In contrast, the heuristic model makes a hot startup, not considering the state of the units before the required dispatch.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
LOAD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	800	800	800	210	210
GCCT OPM	-	-	-	-	-	-	-	-	-	-	-	-	-	50	100	100	150	210	463	800	800	800	463	349
HEURISTIC MODEL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	50	204	351	800	800	800	417	392



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
ST2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30.0	150.	155.	155.	155.	90.1	80.0
ST1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30.0	155.	155.	155.	90.1	80.0
GT5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	73.4	100.	100.	100.	58.8	50.0
GT4	-	-	-	-	-	-	-	-	-	-	-	-	-	50.4	50.4	50.4	75.4	61.1	73.4	100.	100.	100.	58.8	-
GT3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	61.1	73.4	100.	100.	100.	58.8	50.0
GT2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	50.4	50.4	75.4	61.1	73.4	100.	100.	100.	58.8	50.0
GT1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.	100.	100.	58.8	50.0
AUX	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.45	-0.90	-0.90	-0.90	-3.35	-10.8	-11.2	-11.2	-11.2	-11.2	-10.8

CONCLUSIONS AND RECOMENDATIONS

- We propose an original formulation for individual gas and steam turbine units that guarantee specific characteristics of the steam.
- The correct representation of the characteristics are necessary to minimize the impact of thermo-mechanical fatigue produced by the energy output changes required by the system operator and helps to increase the useful time of the CCGT units and the reliability of the CCGT, minimizing future failures.
- We also propose a novel operating constraint that allows for an even load distribution among individual gas turbines - a constraint that is being imposed in real-life CCGTs.
- Improve upon heuristic models in use currently by CCGT operators in the Colombian electric power system.

FUTURE WORKS

- In future research we want to extend this work from a self- to a full Unit-Commitment, considering all power plants of the system. Such a model would help the ISO in order to improve the solution of the dispatch in the Colombian power system, where CCGT plants play an important role.

La manera de empezar
es dejar de hablar y
comenzar a actuar.

Walt Disney

GRACIAS/THANK YOU/OBRIGADO

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