UNIVERSIDAD PONTIFICIA ICAI ICADE COMILLAS MADRID

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA – ICAI

Master Universitario en Sector Eléctrico (Erasmus Mundus)

EMIN: International Master in Economics and Management of Network Industries

"Decision support models in the electric power industry"

Bulk system reliability

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Session MOD.10

Education and Culture DG

ERASMUS MUNDUS

Bibliography

- *IEEE Tutorial Course on Reliability Assessment of Composite Generation and Transmission Systems*. IEEE October 1989
- EPRI *Composite-system reliability evaluation*. EPRI EL-5290. December 1987
- Rivier, M. (1998) *Modelo probabilista de explotación de un sistema eléctrico: contribución a la teoría marginalista*. Tesis doctoral. Universidad Pontificia Comillas.
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Content

➢ Motivation and applications

- Probabilistic operation models
- Uncertainty modeling
- Some models

Motivation

- To give an indication about what it is possible to state with a decision tool
  - Capabilities and limitations
- To become familiar with network modeling techniques
- To give the mathematical foundation

Long term applications

- Network expansion planning
- Selection and evaluation of network investments
- Impact on the generation equipment and consumption
- Interconnections

Medium term applications

- Traditional environment
  - Studies about network performance
  - Generation localization
  - Adequacy assessment/reliability studies
  - Network maintenance
  - Operation planning
- TPA or open access
  - Check transfer capabilities
  - Determine payment for the network use
  - Assign network costs
  - Network remuneration studies
  - Evaluate network contracts

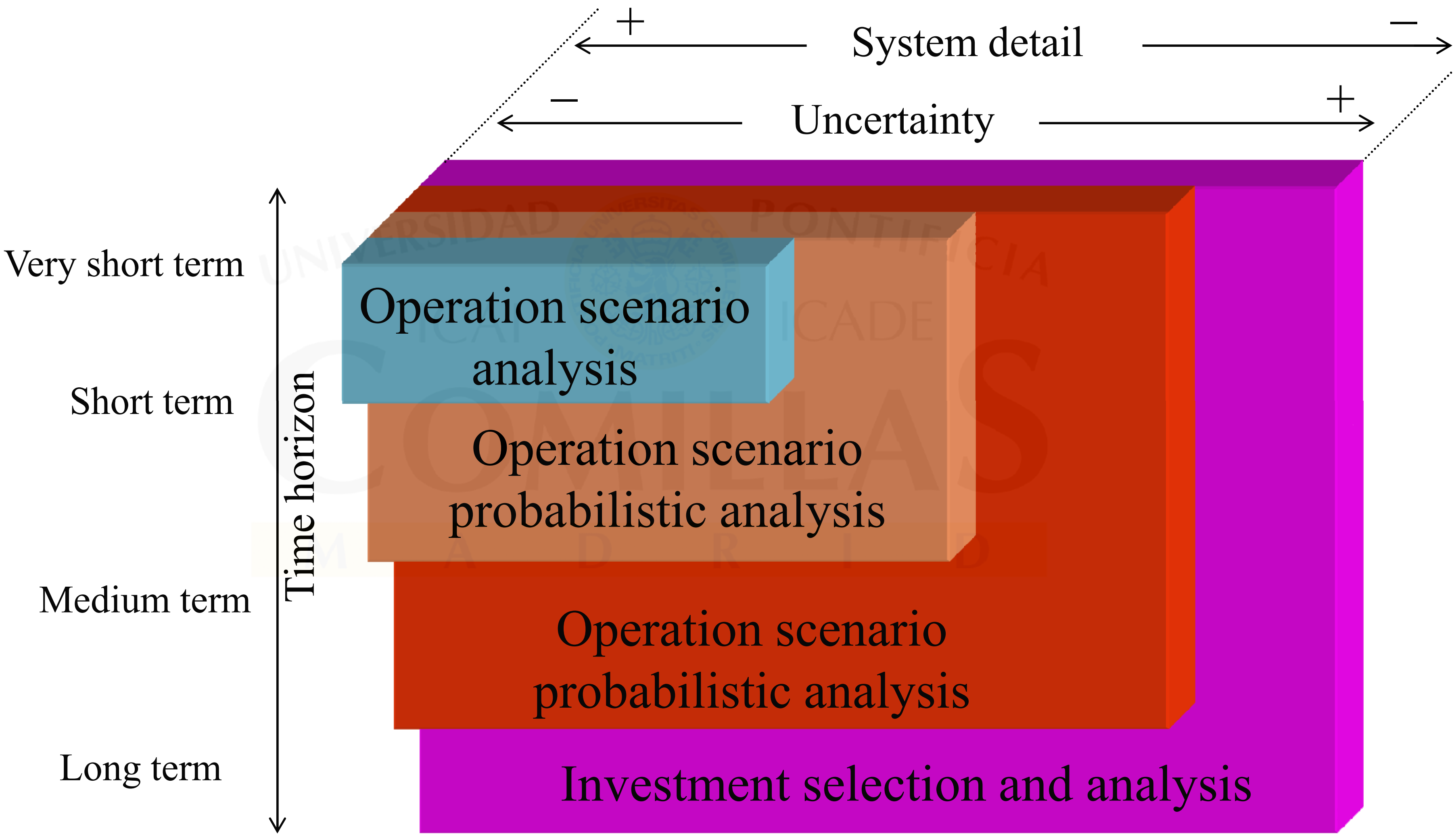
Short term applications

- Check the viability of the generation and consumption dispatch
- Determine nodal marginal prices
- Identify and determine losses
- Identify and determine zonal or local ancillary services
- Decisions about network operation

Very short term applications

- Static analysis of the network
  - Flows
  - Voltages
- Dynamic analysis of the network
  - Stability
  - Voltage collapse

Model hierarchy



Content

- Motivation and applications

➢ Probabilistic operation models

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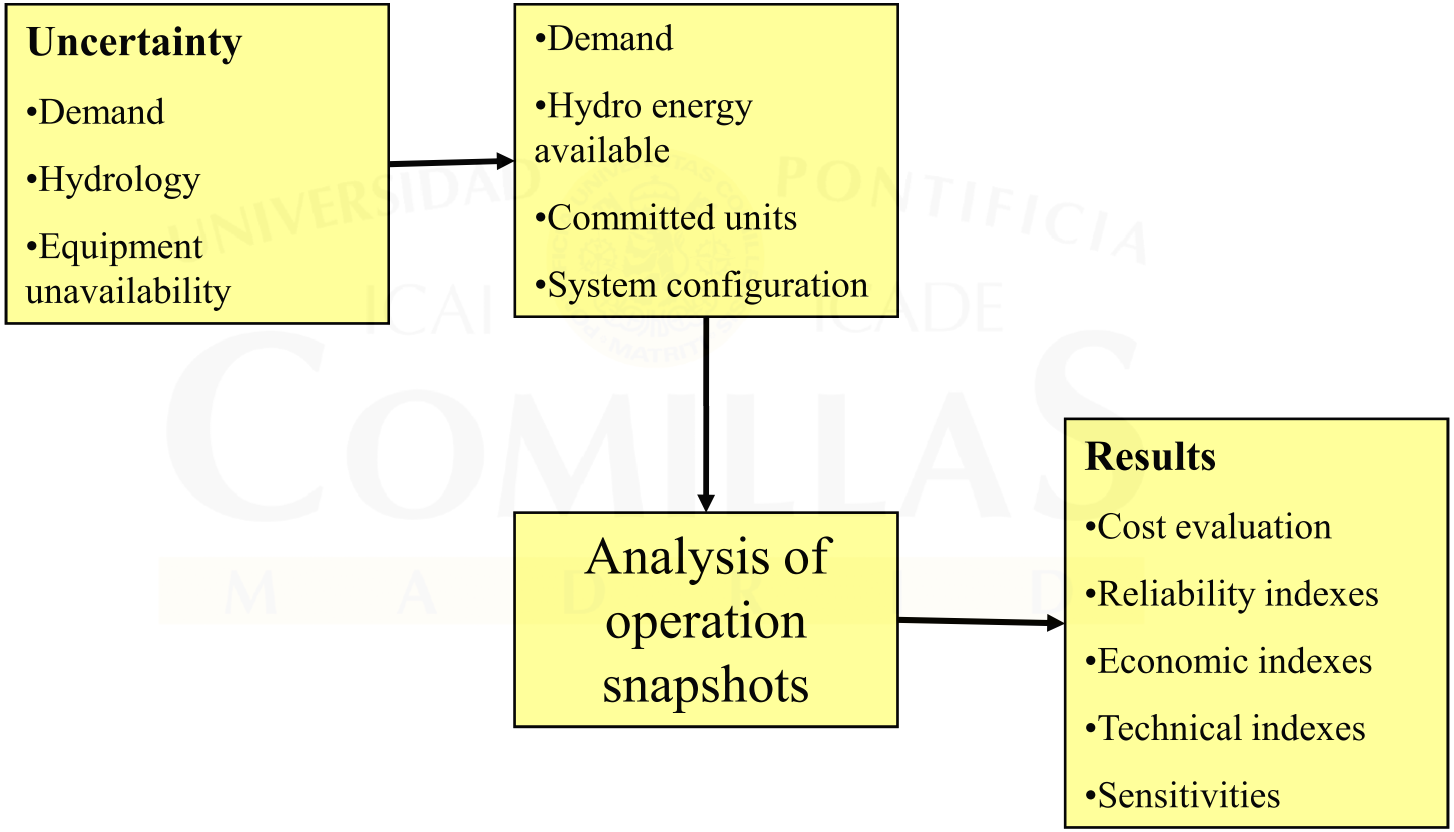
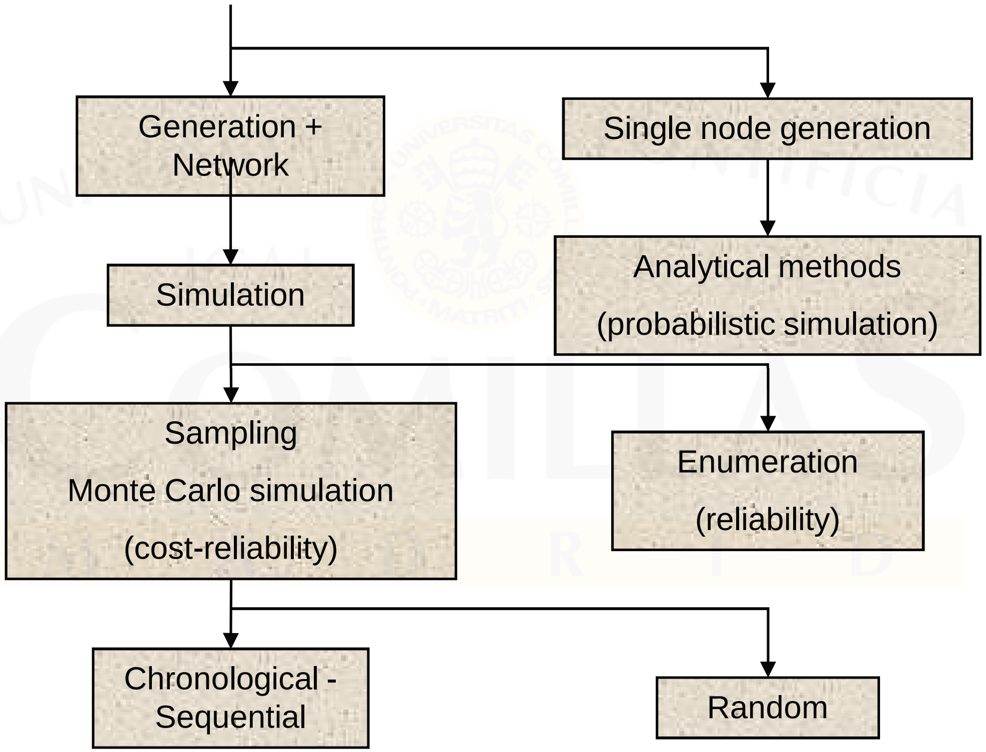
Methods

- Important developments in the field of reliability studies taking into account the transmission network
  - Adequacy assessment
- Extension to cost studies

General structure



Methods


Generation + Network
Single node generation
Simulation
Analytical methods
(probabilistic simulation)
Sampling
Monte Carlo simulation
(cost-reliability)
Enumeration
(reliability)
Chronological - Sequential
Random

Electric network subsystem

- Single node
- Generation/transmission
  - Transportation model (1st Kirchoff's law)
  - DC optimal power flow with or without losses
  - AC optimal power flow
  - Dynamic aspects
- Circuits
  - Branches: lines and transformers.
  - Nodes: substation buses.

Security criterion in contingency dispatch

- Preventive
  - Network and/or generation margin, N-1.
  - Representation in the dispatch model (global optimization, relaxation, scenarios, reserve markets and interruptibility)
- Corrective
  - Generation response margins
  - Load redistribution

Other characteristics to model

- Networks operating limits:
  - Line thermal limits.
  - Node voltages limits.
- Interruptible contracts
- Network emergency operation: e.g., tie and untie, substation reconfiguration
- Violation of preventive security regular criteria in special states (e.g., high cost, emergency)
- Reserves
- Exogenous criteria that condition the dispatch optimality (e.g., fuel quota)

Generation dispatch model

- Optimization
- Simulation + heuristics
  - Sampling of random parameters
  - Logic rules and pre-established strategies to “optimize” the decisions

Content

- Motivation and applications
- Probabilistic operation models

➢ Uncertainty modeling

- Some models

Uncertainty treatment

- Sources
  - Demand
  - Contingencies (availability of generation and network elements)
  - Unregulated inflows or hydro outputs
- Enumeration is not possible by the huge number of states $\Rightarrow$ Monte Carlo simulation

How many samples are needed?

- Let's suppose that 25 samples are enough to determine the mean with a small enough confidence interval
- Failure probability
  - for a generator: 5 %
  - for a line: 0.5 %
- If I want to obtain 25 samples of
  - a generator failure I'll need 500 samples
  - a line failure I'll need 5000 samples
- Therefore, I'll need at least 5000 samples to obtain failures in lines and perhaps non served energy in certain nodes
- A strong computational effort is needed

Stages in Monte Carlo simulation

1. Pseudorandom number generation
2. Random variable generation
3. Simulation or parameter sampling
4. (Variance reduction techniques)
5. Results collection
6. Sampling process stop

Composite operation model

```
SET
cl                 Line characteristics
                   /r, x, pmax, efor/

SET
    samples        number of samples / 1 * 5000 /
    t_aux(g)       thermal units
    h_aux(g)       hydro units
    ii_aux(i,i)    nodes connected by a line

SCALAR
    samplevalue  sample value

PARAMETERS
    efor(g)        unit equivalent forced outage rate [p.u.]

POSITIVE VARIABLES
pns(i)             power non served [GW]

E_FOBJ ..
                   fobj =E= SUM[t, f(t) * alfa(t) * q(t) / k(t) + o(t) * q(t)]
                          + SUM[h, c(h) * [q(h) - rend(h) * b(h)]] + 300*sum[i, pns(i)];
E_DMND(i) ..
                   SUM[t $ it(i,t), q(t)] + SUM[h $ ih(i,h), q(h) - b(h)]
                   - SUM[j $ ii(i,j), p(i,j)]
                   + SUM[j $ ii(j,i), p(j,i)] =E=
                   d(i) - pns(i) ;
pns.up(i) = d(i) ;
```

Line equivalent forced outage rate

Number of samples

Unit equivalent forced outage rate

Power non served

PNS cost in the objective funct

PNS in demand equation

PNS bound

Monte Carlo simulation loop

```
* Initialization of auxiliary sets
ii_aux(i,j) = ii(i,j) ;
t_aux(g)    = t(g)    ;
h_aux(g)    = h(g)    ;

* Loop for all the samples
LOOP (samples,
   ii(i,j) = ii_aux(i,j) ;
   t(g)    = t_aux(g)    ;
   h(g)    = h_aux(g)    ;
*  Sample of thermal unit availability
   LOOP (t_aux(g),
      samplevalue = uniform(0,1) ;
      t(g) $[samplevalue < efor(g)] = no ;
   ) ;
*  Sample of hydro unit availability
   LOOP (h_aux(g),
      samplevalue = uniform(0,1) ;
      h(g) $[samplevalue < efor(g)] = no ;
   ) ;
*  Sample of line availability
   LOOP (ii_aux(i,j),
      samplevalue = uniform(0,1) ;
      ii(i,j) $[samplevalue < dtl(i,j,'efor')] = no ;
   ) ;

*  Solving the problem
   SOLVE MGR USING LP MINIMIZING fobj;

$  INCLUDE MSE_MGR_RESULTADOS.INC
) ;
```

Sample loop

Thermal unit availability

Hydro unit availability

Line availability

DC optimal power flow solution

Monte Carlo simulation (I)

- It is used when the number of states of the random parameters is very huge (e.g., contingencies)
- Estimate the mathematical expectation of operating costs and/or reliability measures
- Simulate is equivalent to integrate or sample in hyperspace of random parameters with a known probability density function
- Determine sample mean, mean variance, confidence interval.
- Stop sampling when confidence interval is lower than a certain tolerance.

Monte Carlo simulation (II)

- Quadratic behavior (4 times more samples divides by 2 the confidence interval)
- Events with a small probability and a huge value of the objective function cause high variances (it is the usual case of reliability indexes). Therefore, many samples are needed
- Variance reduction techniques
  - Common random numbers, antithetic variables, control variable, importance sampling, stratified sampling
  - Allow to reduce the size of the confidence interval of the mean without disturbing its value for a certain number of samples or, alternatively, achieve the desired precision with a lower sampling effort.

Variance reduction techniques VRT (I)

- Usually, it is impossible to know in advance the variance reduction to be achieved, or even if it is going to be reduced. We have to experiment considering the real system to analyze.
- You have to know the model in detail that reproduces the system behavior.
- The use of VRT can be understood as a way of taking advantage of information about the implied system.
- Imply a computational over-cost to do certain preliminary samples or auxiliary computations in the same simulation process.

Variance reduction techniques VRT (II)

- Common random numbers or correlated sampling or comparative simulation or synchronized pairs
  - Do sampling for different system configurations with the same set of random numbers being used each one for the same function in sampling process.
- Antithetic variables
  - It is based on the idea of introducing a negative correlation between two consecutive samples. It consists of the use of complementary random numbers in two consecutive simulations.

Variance reduction techniques VRT (III)

- Control variable
  - The basic idea is to use the results of a simpler model to predict or explain part of the variance of the value to estimate. A previous computation of the expected value of the control variable is needed. This computation has to be very quick compared to those of the variable to estimate.
- Importance sampling
  - The random variable to estimate is replaced by another with the same mean but different variance. The probability density function used in the sampling process is modified to center it around the area of interest. Sampling probable but not interesting events is avoided.

Variance reduction techniques VRT (IV)

- Stratified sampling
  - The intuitive idea of this technique is similar to the previous one but in a discrete version. It consists on taking more samples of the random variable in the areas of greater interest. The variance is reduced by concentrating the simulation effort in the more relevant strata.

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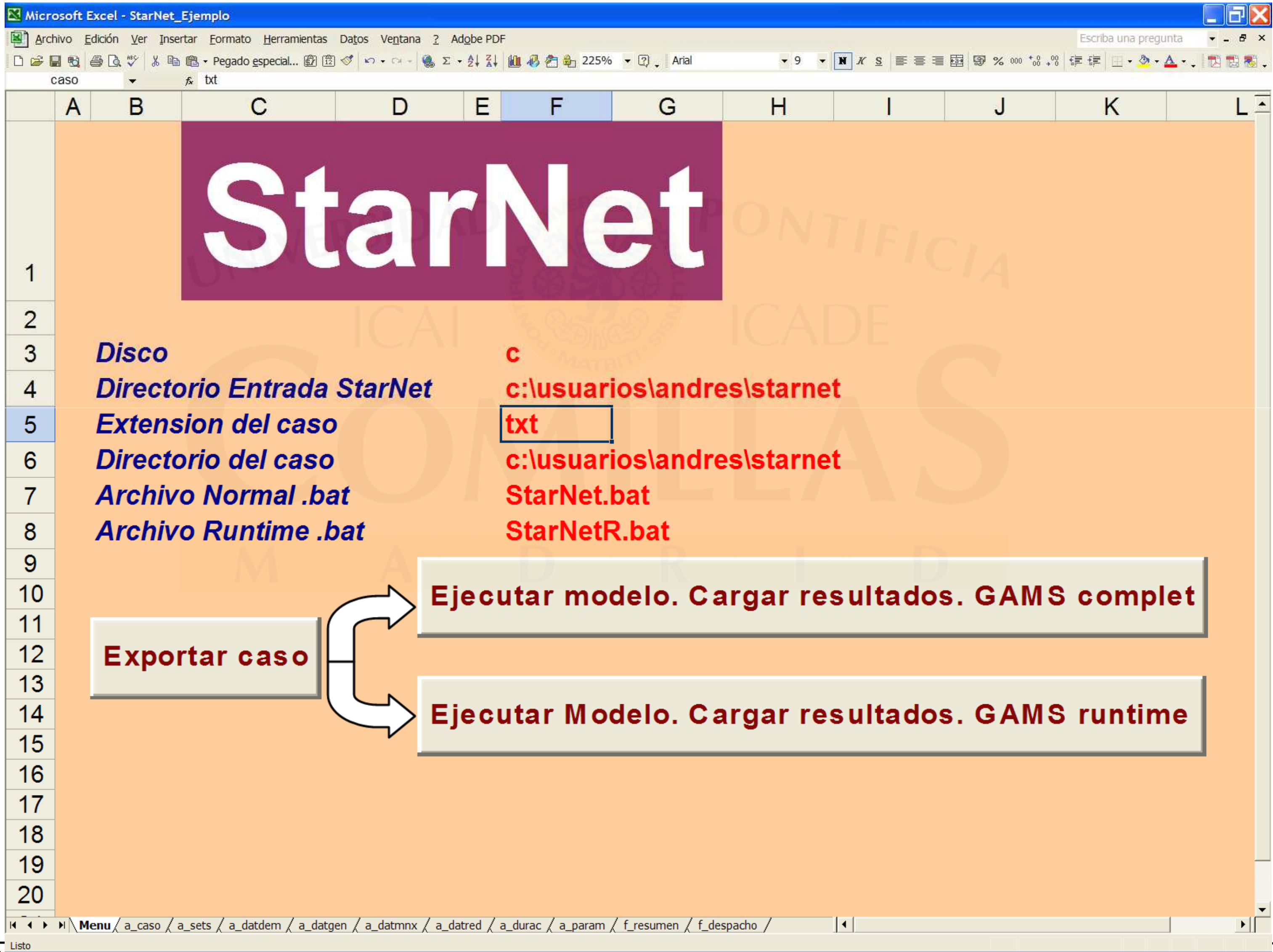
➢ Some models

Some IIT transmission network planning models

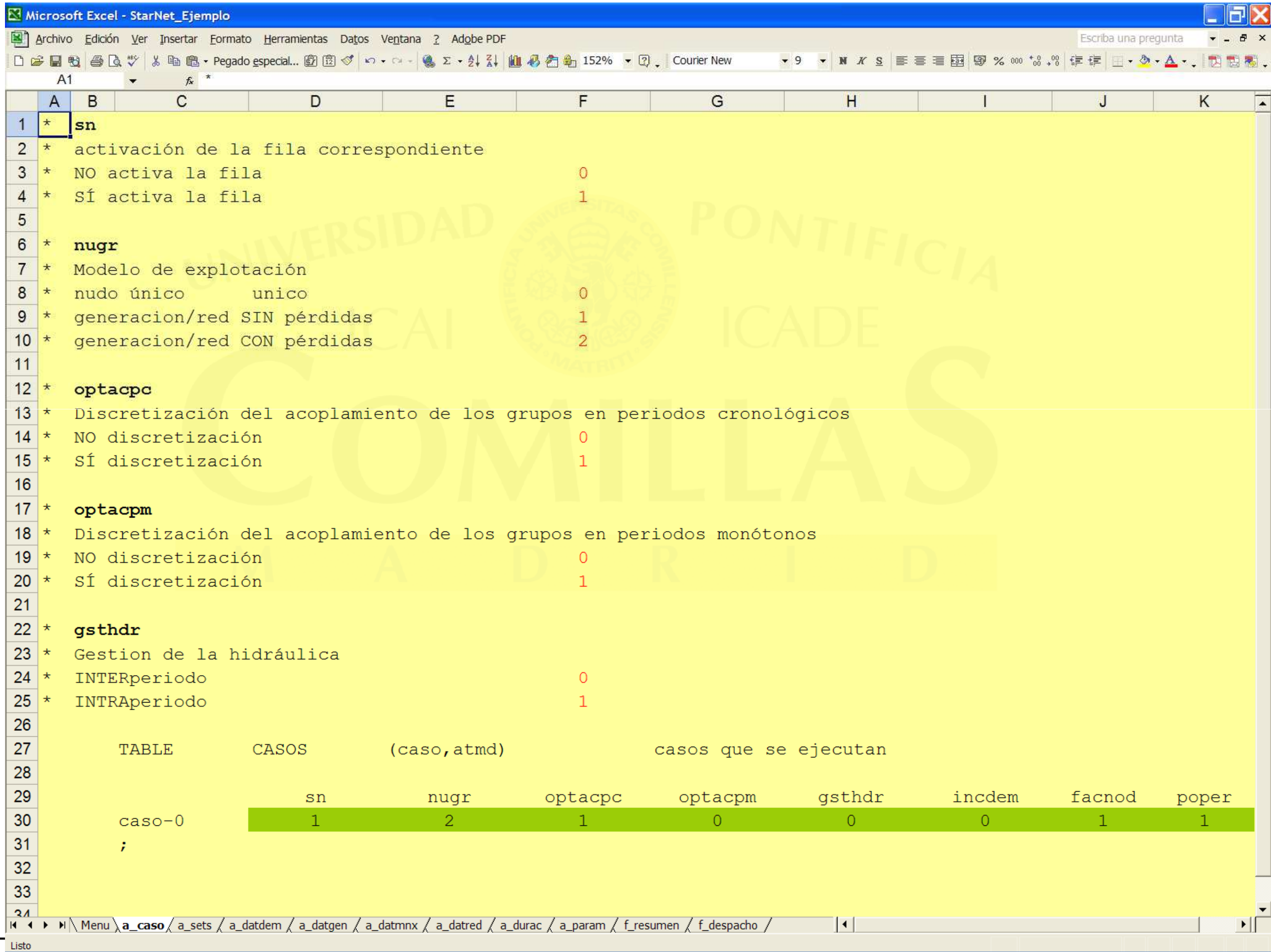
- Medium term application
  - StarNet/RD for different companies in Dominican Republic
  - SIMUSIS/SIMUMER/SIMUPLUS for REE
- Long term application
  - PERLA/CHOPIN for REE

StarNet/RD (i)

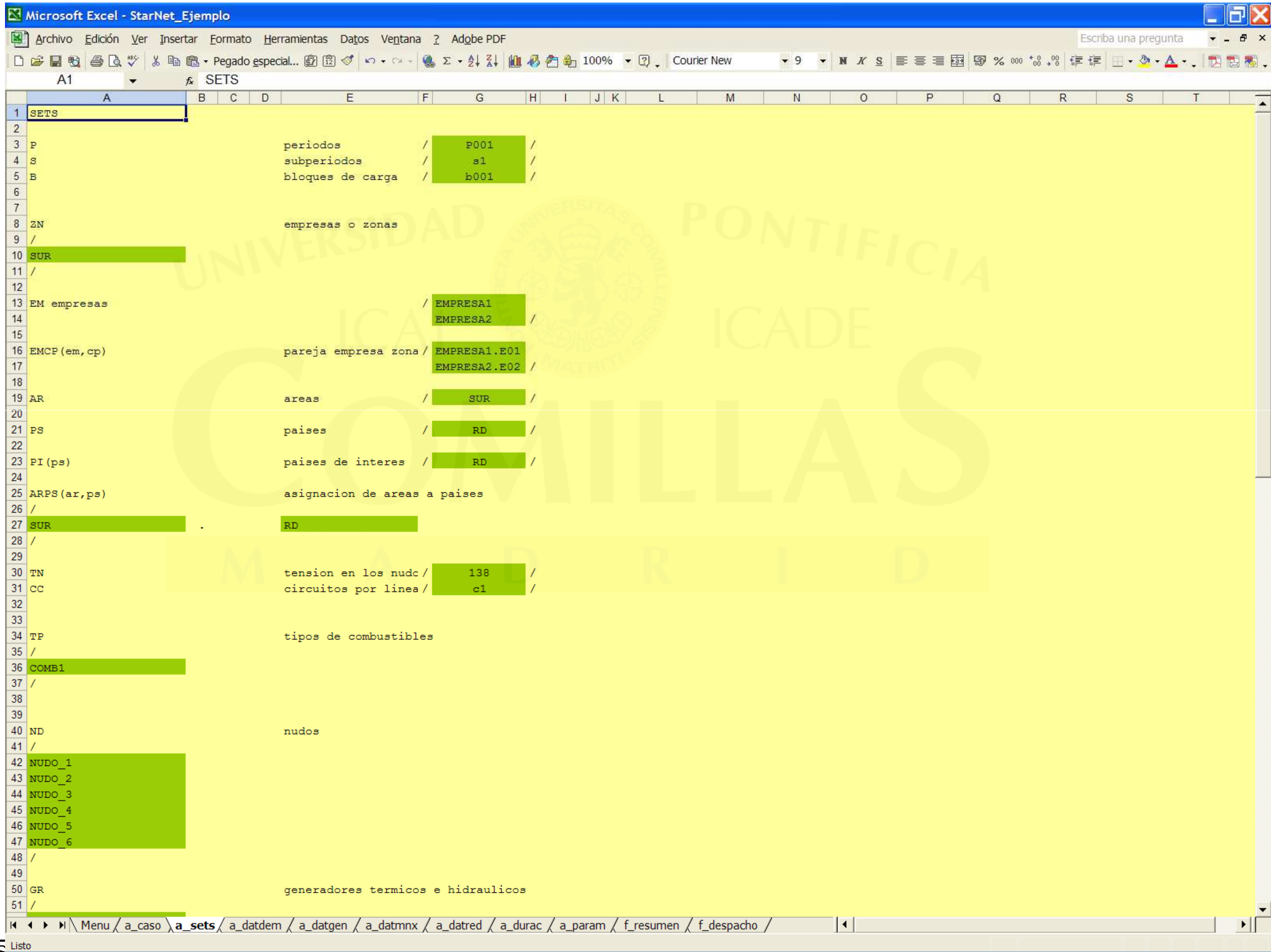
(www.iit.upcomillas.es/aramos/StarNet.htm)



StarNet/RD (ii)



StarNet/RD (iii)



	A	B	E	F	G	H
1	SETS					
2						
3	P		periodos	/	P001	/
4	S		subperiodos	/	s1	/
5	B		bloques de carga	/	b001	/
6						
7						
8	ZN		empresas o zonas			
9	/					
10	SUR					
11	/					
12						
13	EM empresas			/	EMPRESA1	
14					EMPRESA2	/
15						
16	EMCP(em,cp)		pareja empresa zona	/	EMPRESA1.E01	
17					EMPRESA2.E02	/
18						
19	AR		areas	/	SUR	/
20						
21	PS		paises	/	RD	/
22						
23	PI(ps)		paises de interes	/	RD	/
24						
25	ARPS(ar,ps)		asignacion de areas a paises			
26	/					
27	SUR	.	RD			
28	/					
29						
30	TN		tension en los nudc	/	138	/
31	CC		circuitos por linea	/	c1	/
32						
33						
34	TP		tipos de combustibles			
35	/					
36	COMB1					
37	/					
38						
39						
40	ND		nudos			
41	/					
42	NUDO_1					
43	NUDO_2					
44	NUDO_3					
45	NUDO_4					
46	NUDO_5					
47	NUDO_6					
48	/					
49						
50	GR		generadores termicos e hidraulicos			
51	/					

StarNet/RD (iv)

	A	B	C	D
1	TABLE	DATDEM	(nd,	p,s,b, atd)
2				
3			b001.dm	
4	NUDO_1	.p001.s1	280.0	
5	NUDO_2	.p001.s1	240.0	
6	NUDO_3	.p001.s1	220.0	
7	NUDO_4	.p001.s1	150.0	
8	NUDO_5	.p001.s1	110.0	
9	NUDO_6	.p001.s1	110.0	

Menu / a_caso / a_sets / a_datdem / a_datgen / a_datmnx / a_datred / a_durac / a_param / f_resumen / f_despacho

StarNet/RD (v)

Microsoft Excel - StarNet_Ejemplo

A1 TABLE

	A	B	C	D	E	F
1	TABLE	DATGEN	(gr,atg)			
2						
3		YN	PMX	PMN	SSAA	CARR
4	TERM_1_1	0	360.0	180.0	1	0
5	TERM_1_2	0	100.0	50.0	1	0
6	TERM_2_1	0	500.0	250.0	1	0
7	TERM_2_2	1	250.0	125.0	1	0
8	TERM_3_1	1	320.0	160.0	1	0
9	TERM_3_2	1	420.0	210.0	1	0
10	TERM_4_1	1	180.0	90.0	1	0
11	TERM_4_2	1	160.0	80.0	1	0
12	TERM_5_1	1	190.0	95.0	1	0
13	TERM_5_2	1	140.0	70.0	1	0
14	TERM_6_1	1	220.0	110.0	1	0
15	TERM_6_2	1	320.0	160.0	1	0
16	+					

	A	B	C	D	E	F
17		TC1	CSTC1	A	Q	base
18	TERM_1_1	1	1000	86.000	0	0
19	TERM_1_2	1	1000	85.000	0	0
20	TERM_2_1	1	1000	76.000	0	0
21	TERM_2_2	1	1000	75.000	0	0
22	TERM_3_1	1	1000	66.000	0	0
23	TERM_3_2	1	1000	65.000	0	0
24	TERM_4_1	1	1000	56.000	0	0
25	TERM_4_2	1	1000	55.000	0	0
26	TERM_5_1	1	1000	51.000	0	0
27	TERM_5_2	1	1000	50.000	0	0
28	TERM_6_1	1	1000	46.000	0	0
29	TERM_6_2	1	1000	45.000	0	0
30	+					

	A	B
31		E01
32	TERM_1_1	100
33	TERM_1_2	100
34	TERM_2_1	100
35	TERM_2_2	100
36	TERM_3_1	100
37	TERM_3_2	100
38	TERM_4_1	100
39	TERM_4_2	100
40	TERM_5_1	100
41	TERM_5_2	100
42	TERM_6_1	100
43	TERM_6_2	100
44	+	

	A	B
45		M001
46	TERM_1_1	0
47	TERM_1_2	0
48	TERM_2_1	0
49	TERM_2_2	0
50	TERM_3_1	0
51	TERM_3_2	0

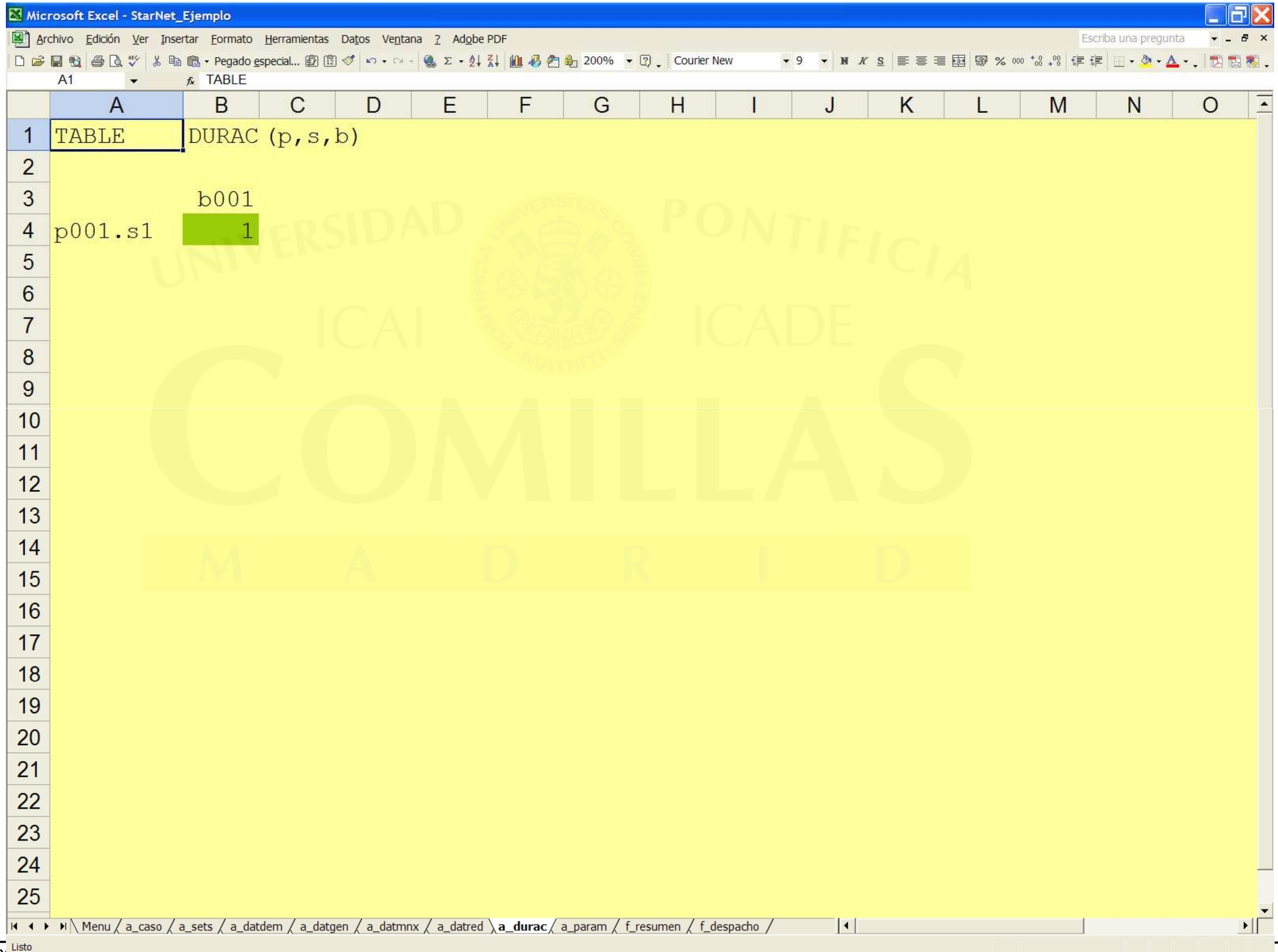
Menu / a_caso / a_sets / a_datdem / **a_datgen** / a_datmnx / a_datred / a_durac / a_param / f_resumen / f_despacho

Listo

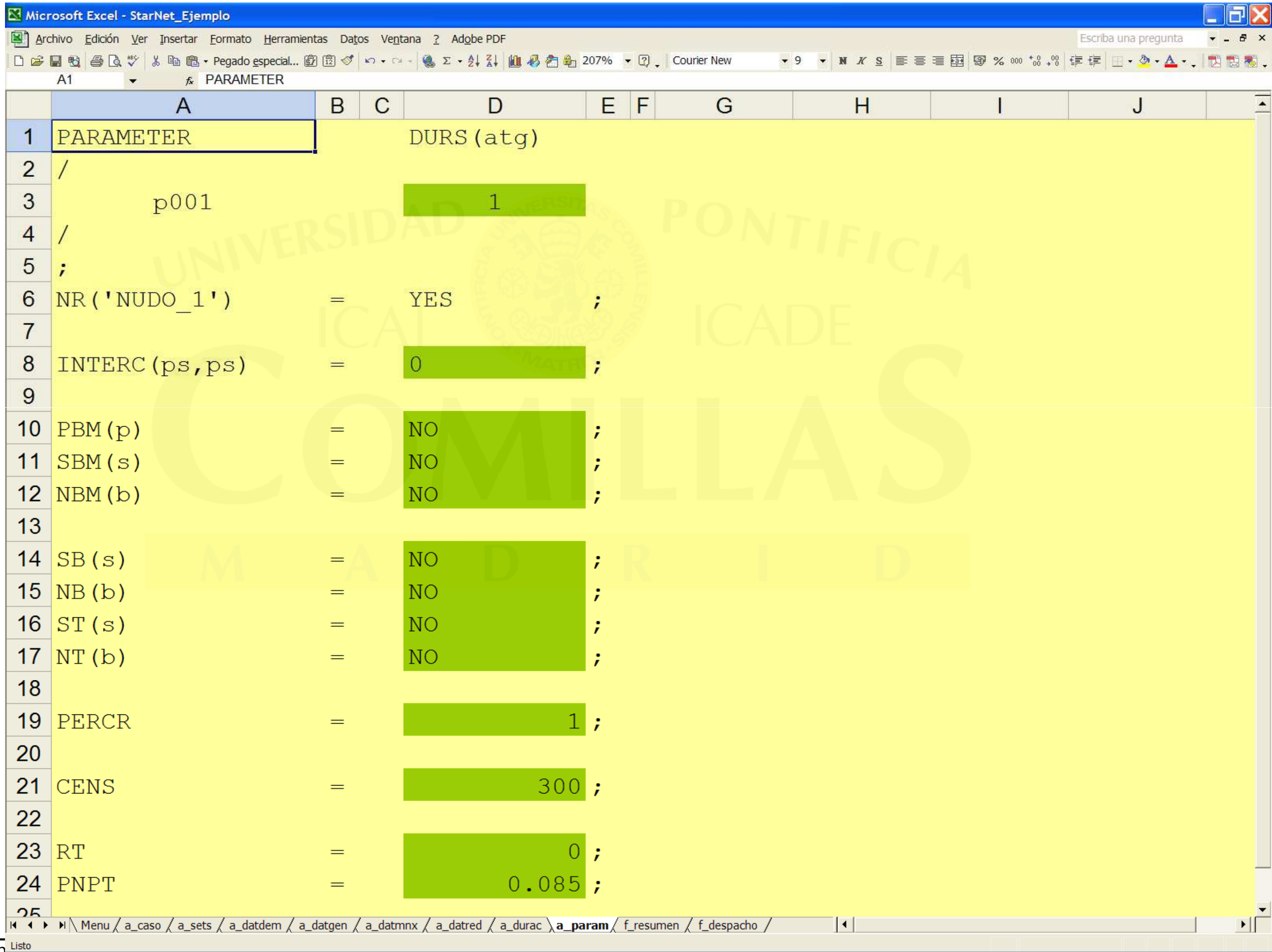
StarNet/RD (vi)

	A	B	C	D	E	F	G	H	I	J	K
1	TABLE		DATRED				(ni,nf,cc,atl)				
2							r	x	flmx	status	csl
3	NUDO_1	.	NUDO_2	.	c1		0.00750	0.04500	600.00	1	1
4	NUDO_2	.	NUDO_3	.	c1		0.00750	0.04500	600.00	1	1
5	NUDO_2	.	NUDO_4	.	c1		0.00750	0.04500	600.00	1	1
6	NUDO_3	.	NUDO_5	.	c1		0.00750	0.04500	600.00	1	1
7	NUDO_4	.	NUDO_5	.	c1		0.00750	0.04500	600.00	1	1
8	NUDO_5	.	NUDO_6	.	c1		0.00750	0.04500	600.00	1	1

StarNet/RD (vii)



StarNet/RD (viii)



	A	B	C	D	E
1	PARAMETER			DURS(atg)	
2	/				
3	p001			1	
4	/				
5	;				
6	NR('NUDO_1')	=		YES	;
7					
8	INTERC(ps,ps)	=		0	;
9					
10	PBM(p)	=		NO	;
11	SBM(s)	=		NO	;
12	NBM(b)	=		NO	;
13					
14	SB(s)	=		NO	;
15	NB(b)	=		NO	;
16	ST(s)	=		NO	;
17	NT(b)	=		NO	;
18					
19	PERCR	=		1	;
20					
21	CENS	=		300	;
22					
23	RT	=		0	;
24	PNPT	=		0.085	;

StarNet/RD (ix)

Microsoft Excel - StarNet_Ejemplo

	A	B	C	D
1	Fecha:	03.12.04	Hora:	16:12:58
2	DESPACHO POR EMPRESAS [MW]			
3				
4	PERIODO	p001		
5	SUBPERIODO	s1	ENERGIA	
6	BLOQUE	b001	[MWh]	
7				
8	EMPRESA1			
9				
10	TERM_2_2	0	0	
11	TERM_3_1	0	0	
12	TERM_3_2	0	0	
13	TERM_4_1	125.923	125.923	
14	TERM_4_2	160	160	
15	TERM_5_1	190	190	
16	TERM_5_2	140	140	
17	TERM_6_1	220	220	
18	TERM_6_2	320	320	
19				
20	EMPRESA2			
21				
22				
23				
24	PNS	0	0	
25	PINT	0	0	
26	DRRC	0	0	
27	DRTC	0	0	
28				
29	PERDIDAS	45.923	45.923	
30	SSAA	0	0	
31				
32	DEMANDA	1110	1110	
33				
34				
35				
36	Costo Marginal	60.965	60.965	

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StarNet/RD (x)

Microsoft Excel - StarNet_Ejemplo

	A	B	C	D	E	F	G	H	I	J	K
1	Fecha:	03.12.04	Hora:	16:12:58							
2		PERIODO	p001	SUBPERIODO	s1	BLOQUE	b001				
3											
4	PLANTA	BARRA	POT MAX	U.BASE	DESPACHO	%DESPACHO	FACT NOD	MULT LAGR		CVP	CVD
5			[MW]	0 no 1 si	[MW]	[%]	[p.u.]	[$/MWh]		[$/MWh]	[$/MWh]
6	TERM_6_2	NUDO_6	320	0	320	100	0.834476	-	-	45	53.926
7	TERM_6_1	NUDO_6	220	0	220	100	0.834476	-	-	46	55.124
8	TERM_5_2	NUDO_5	140	0	140	100	0.885272	-	-	50	56.48
9	TERM_5_1	NUDO_5	190	0	190	100	0.885272	-	-	51	57.609
10	TERM_4_2	NUDO_4	160	0	160	100	0.918564	-	-	55	59.876
11	TERM_4_1	NUDO_4	180	0	125.923	70	0.918564	-	-	56	60.965
12	TERM_3_2	NUDO_3	420	0	0	0	0.939174	-	-	65	69.21
13	TERM_3_1	NUDO_3	320	0	0	0	0.939174	-	-	66	70.274
14	TERM_2_2	NUDO_2	250	0	0	0	0.963743	-	-	75	77.822
15											
16	Costo marginal en NUDO_1	60.965									
17	Reserva Resultante	54.077	Porciento	4.678							

Menu / a_caso / a_sets / a_datdem / a_datgen / a_datmnx / a_datred / a_durac / a_param / f_resumen / f_despacho

CHOPIN

- G. Latorre, J.I. Perez-Arriaga CHOPIN, A HEURISTIC MODEL FOR LONG TERM TRANSMISSION EXPANSION PLANNIG IEEE Transactions on Power System, Vol. 9, No. 4, November 1994

PLAER

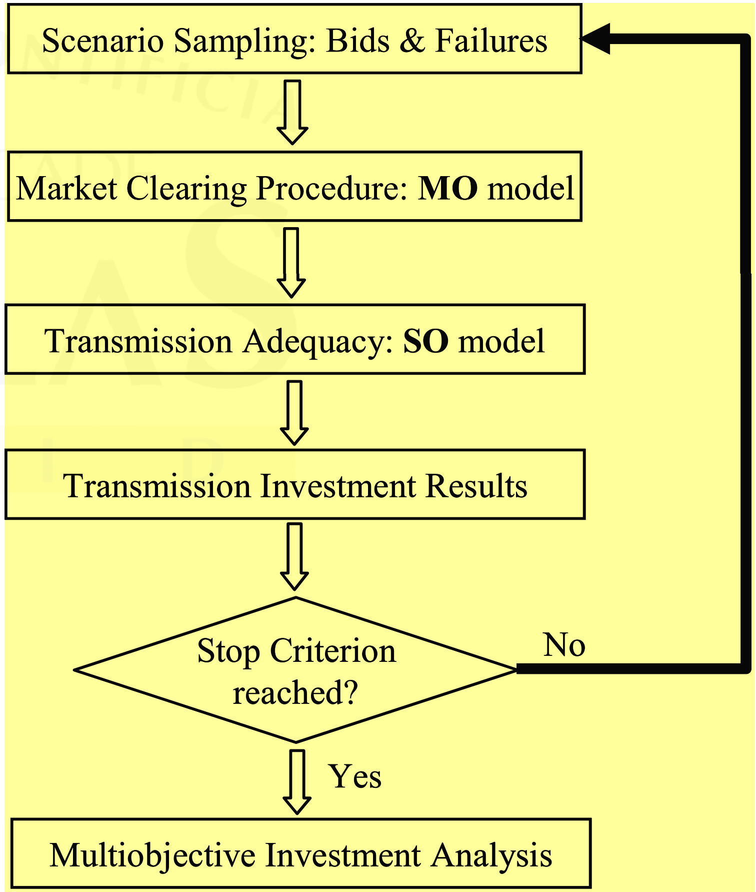
- de Dios, R., Sáiz, A., Melsión, J.L. y Bassy, A., “PLAER. Strategic Transmission Network Planning”. 11TH Power System Computation Conference, August 1993

PERLA

- J.F. Alonso, A. Sáiz, L. Martín G. Latorre, A. Ramos, I.J. Pérez-Arriaga *PERLA: An Optimization Model for Long Term Expansion Planning of Electric Power Transmission Networks* IIT-91-009 January 1991 (http://www.iit.upcomillas.es/aramos/papers/COIMBRA.pdf)

SIMUPLUS (i)

- Determine incremental investment needs in transmission network for the medium term in electricity markets



P. Sánchez-Martín, A. Ramos, J.F. Alonso
Probabilistic mid-term transmission planning in a liberalized market IEEE Transactions on Power Systems 20 (4): 2135-2142 Nov 2005

(http://www.iit.upcomillas.es/aramos/papers/TPWRS-00679-2004.pdf)

SIMUPLUS (ii)

1. Monte Carlo sampling:
   – Demand bids and generation offers
   – Units and circuits availability
   – Hydro and wind generation
2. Single node market clearing
   – Losses included as additional demand
3. Network constraint evaluation penalizing deviations with respect to market clearing
   – DC load flow, flow limits, losses
   – N-1 contingencies
4. Determine sensitivities (derivative of the objective function with respect to investment):
   – Improvement in existing circuits
   – New circuit expansion

SIMUPLUS (iii)

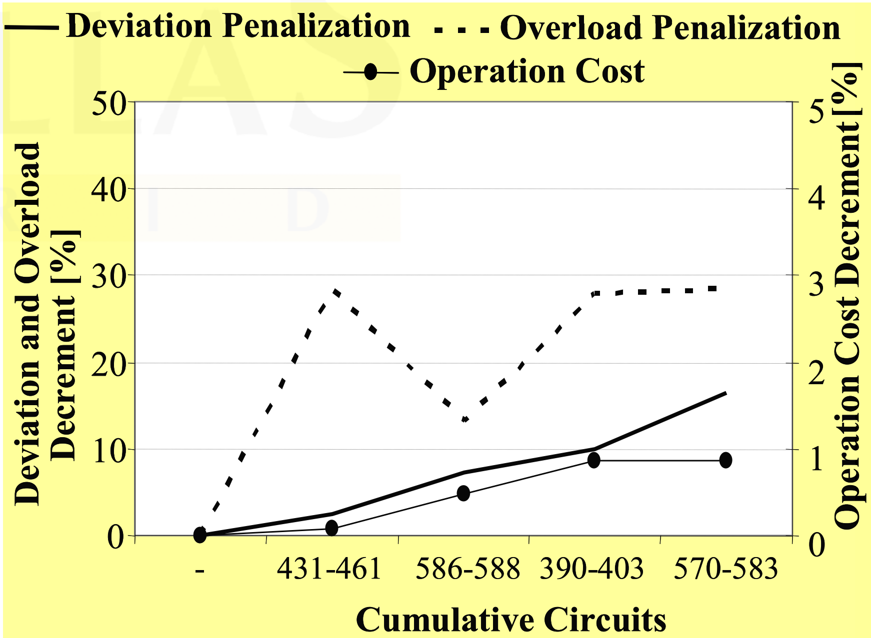
5. Investment multi-attribute analysis
   - Weigh sensitivities average, confidence interval, validity range, investment needs, environmental impact, etc.
   - Investment selection
6. Repeat all the process

SIMUPLUS (iv)

Spanish Iterative Investment Ranking

Stage	Candidates	Sensitivity mean [M$/M$]	Confidence interval [%]	Validity range [MW]	Multi-attribute value
No circuit is added (initial stage)					
1	**431-461**	**-5.622**	**8.6**	**296**	**1.505**
	390-403	-3.365	7.9	119	0.767
	570-583	-1.254	63.4	131	0.727
Circuit 431-461 is added					
2	**586-588**	**-3.275**	**57.5**	**138**	**1.162**
	390-403	-3.352	7.9	107	0.941
	570-583	-1.849	56.8	128	0.897
Circuits 431-461 and 586-588 are added					
3	**390-403**	**-3.633**	**6.9**	**157**	**1.468**
	570-583	-0.289	39.1	138	0.894
	424-520	-2.841	7.9	6	0.638
Circuits 431-461, 586-588 and 390-403 are added					
4	**570-583**	**-0.587**	**51.4**	**129**	**1.434**
	424-520	-2.930	7.8	5	0.821
	500-567	-1.784	10.1	30	0.745
Circuits 431-461, 586-588, 390-403 and 570-583 are added					
5	**457-498**	**-0.495**	**19.8**	**83**	**1.293**
	424-520	-3.027	7.6	7	0.933
	500-567	-1.665	10.9	21	0.774
No more circuits are added					

- 623 nodes and 1021 circuits, 165 thermal units and 76 hydro units. 12 network expansion alternatives. Sampling of 100 scenarios in each stage and obtain the 3 best alternatives.



Summary

- Where to use a composite reliability model
- Some characteristics to be considered into this model
- Mathematical techniques used to solve the model
- Some real applications

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