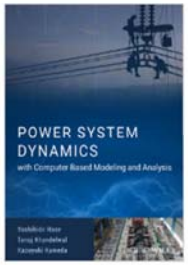
30th ETAP User Group

過渡安定度解析

ETAP による Industrial System Model の解析例

2019年11月26日
株式会社エルテクス設計
亀田 和之



Power System Dynamics with Computer-Based Modeling and Analysis

Yoshihide Hase, Tanuj Khandelwal, Kazuyuki Kameda

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Kazuyuki Kameda does engineering and consulting for Electrical and Control Systems at Eltechs Engineering & Consulting Co., Ltd, in Japan.

Wiley New Book (Wiley 新刊紹介)

Power System Dynamics with Computer Based Modeling & Analysis

by Y.Hase, T.Khandelwal and K.Kameda

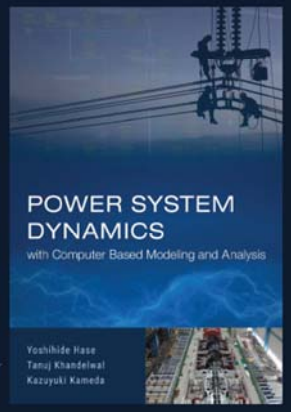
by Hase
Wiley
2nd-ed2013

by Hase
Maruzen
3rd-ed2015

Experience

ETAP Solved Examples

Best Practices including IEEE & IEC



Wiley 1112 pages!
(will be published on February 2020)

Part A: Power Systems Engineering Theories
Part B: Computational Methodologies
Part C: ETAP Examples & Analysis (ETAP Practices)

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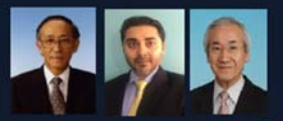
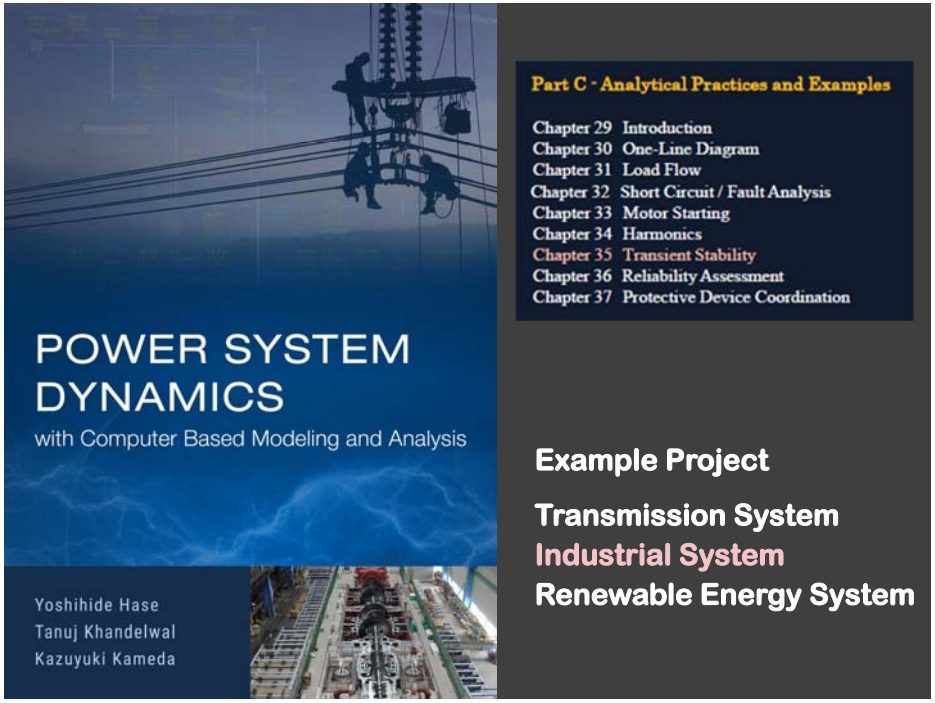
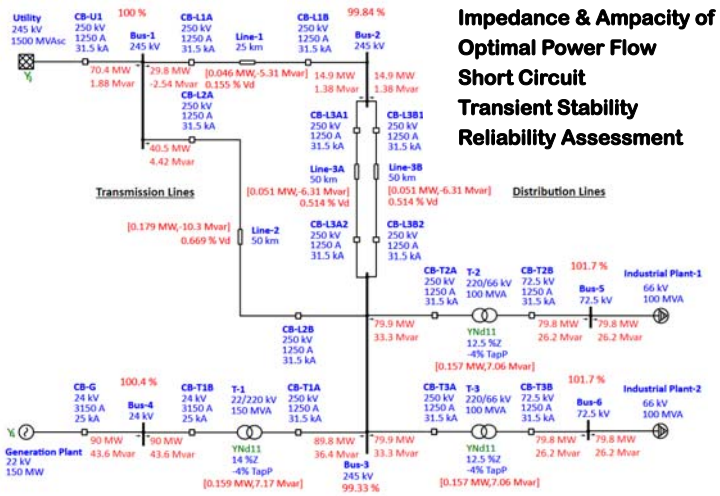


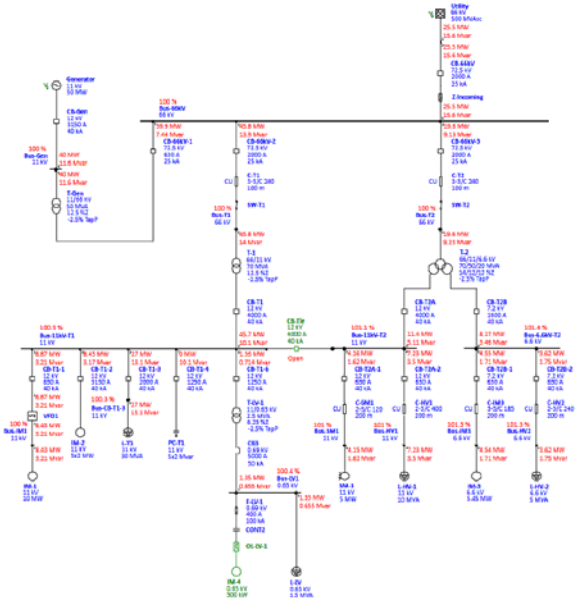


Transmission System



- Load Flow
- Impedance & Ampacity of Transmission line
- Optimal Power Flow
- Short Circuit
- Transient Stability
- Reliability Assessment

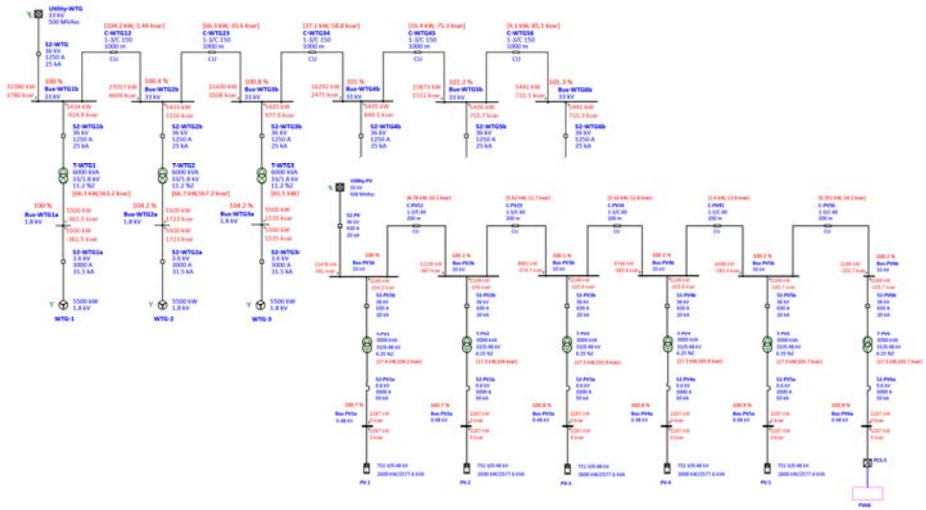
Industrial System

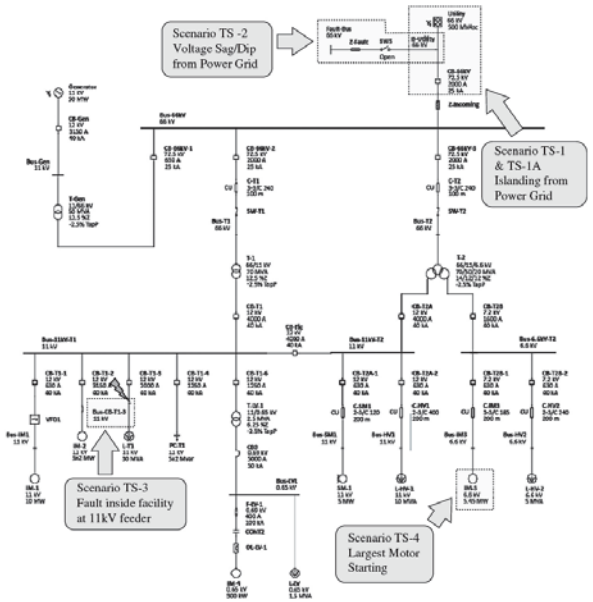


- Load Flow
- Cable Ampacity & Cable Sizing
- Underground Cables
- Short Circuit
- Grounding Grid System
- Motor Starting
- Harmonic
- Transient Stability

Renewable Energy System

- Load Flow
- Short Circuit





Industrial System Transient Stability

解析項目

- **TS-1** 商用停電
- **TS-2** 商用瞬低
- **TS-3** 母線短絡
- **TS-4** 電動機始動

商用系統、母線、変圧器のデータ

Power grid

Operating mode	Swing
Nominal kV	66 kV
Short-circuit capacity	500 MVA
X/R ratio	20

Buses (nodes)

Nominal kV	66 kV, 11 kV, 6.6 kV, 0.65 kV

Transformers

• Two-winding transformer

	Rated kV							
ID	Primary	Secondary	MVA	%Z	X/R	Connection	Grounding	Tap
T-Gen	11	66	50	12.5	45	YNd11	Solid	As per required
T-1	66	11	70	12.5	45	Dyn11	Solid	
T-LV-1	11	0.65	2.5	6.25	6	Dyn11	Solid	

• Three-winding transformer

ID	Winding	Rated kV	MVA	%Z	X/R	Connection	Grounding	Tap
T-2	Primary	66	70	14[a]	40	Wye	Solid	As per required
	Secondary	11	50	12[b]	40	Delta		
	Tertiary	6.6	20	12[c]	40	Delta		

[a] Primary-secondary.
[b] Primary-tertiary.
[c] Secondary-tertiary.

電力潮流計算に必要なデータ

- 潮流計算に必要なデータを入力する。
- 潮流計算を実行する。
- 初期潮流のチューニング（事故・系統動揺が起こる前の電力潮流状態）

負荷データ（誘導電動機、同期電動機、一括負荷）

Loads

• Induction motor

Motor ID	MW	Pole	kV	% Load	LRC (%)	PF Ir (%)	LRTrq (%)	MaxTrq (%)	Slip (%)	PF (%)	Eff (%)	Current (A)	Q'ty.
IM-1	10	4	11	80	650	7.59	35.29	220.8	1.5	93.44	94.92	591.8	1
IM-2	2	4	11	80	650.08	15.05	99.65	220.2	1.5	93.2	95.45	118	5
IM-3	5.45	4	6.6	80	549.9	20.01	65.02	165	1.5	92.06	95.55	542	1
IM-4	300	4	0.65	100	600	20.06	35	210	0	91.99	93.11	311.1	1

• Synchronous motor

Motor ID	MW	Pole	kV	% Load	LRC (%)	PF Ir (%)	PF (%)	Eff (%)	Current (A)	Quantity
SM-1	5	2	11	80	650	9.2	93.15	96.3	292.6	1

• Lumped loads

Lumped Load ID	MVA	kV	PF (%)	%Motor Load	%Static Load	LRC (%)	X/R	% Load
L-HV-1	10	11	90	80	20	600	10	80
L-HV-2	5	6.6	90	80	20	600	10	80
L-LV	1.5	0.65	90	80	20	600	2.38	100
L-T1	30	11	90	80	20	650	10	100

発電機、電力コンデンサ、ケーブルのデータ

Synchronous generator

Operating mode	Voltage control
Rating	50 MW, 11 kV, 2 poles, %PF = 90, %Eff. = 98%
Generation	40 MW, %*V* = 100%
Subtransient impedance	*Xd*" = 25%
Transient reactance	*Xd*' = 35%
Synchronous reactance	*Xd* = 99%
X/R ratio	*X*"*d*/Ra = 25

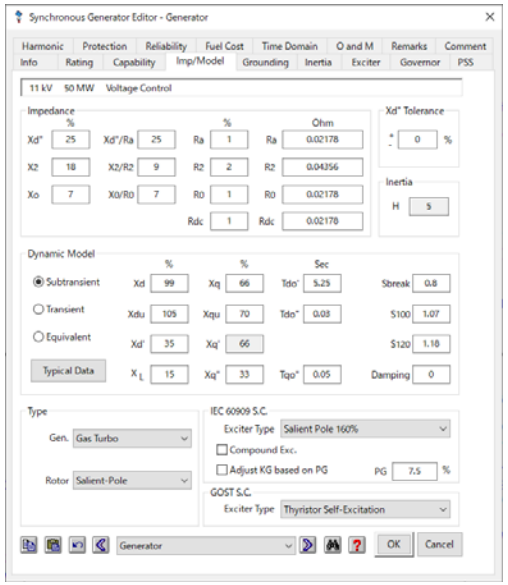
• Power capacitors

Nominal kV	11 kV
Capacity	2Mvar × 5 banks

• Feeder cables

Cable ID	Voltage (kV)	Type	Core	Size (mm^2)	Q'ty	Length (m)
C-T1	66	XLPE	3	240	3	100
C-T2	66	XLPE	3	240	3	100
C-SM1	11	XLPE	3	120	2	200
C-HV1	11	XLPE	3	400	2	200
C-IM3	6.6	XLPE	3	185	3	200
C-HV2	6.6	XLPE	3	240	2	200

発電機定数（初期過渡定数 : Subtransient)

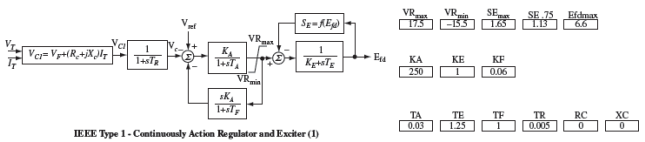


過渡安定度計算に必要なデータ

- 過渡安定度計算に必要なデータを追加入力する。
- 発電機定数（初期過渡定数 : Subtransient)
- AVR, Governor, PSS
- 慣性定数
- 電動機のダイナミックモデリング

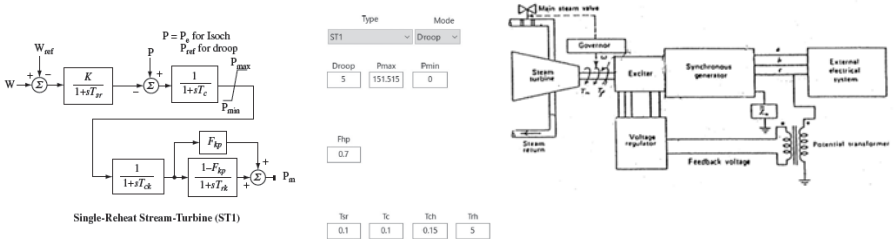
AVR (IEEE Type 1), Governor (ST1), Inertia (H)

- AVR model = >IEEE Type 1:



IEEE Type 1 - Continuously Action Regulator and Exciter (1)

- Governor model => ST1 model:

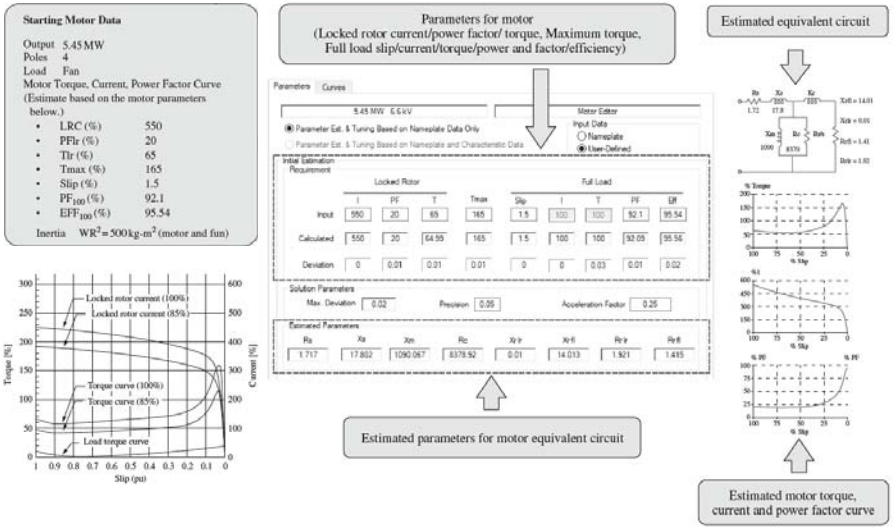


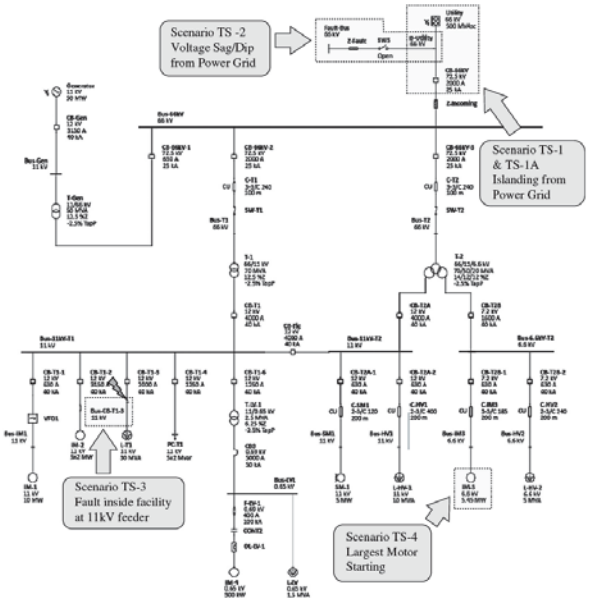
Single-Reheat Stream-Turbine (ST1)

- Inertia of generator and prime mover:

H = 2 MW-s/MVA (WR2 = 6751 kg/m^2) total for the generator and prime mover.

誘導電動機 (5450kW, 4 pole) のダイナミックモデリング





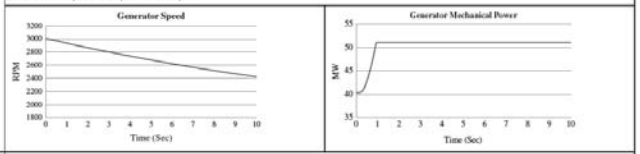
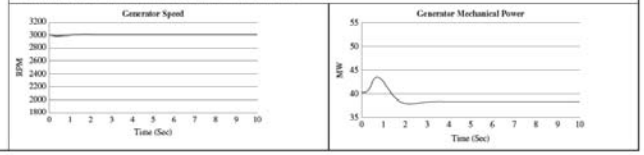
Industrial System Transient Stability

解析結果

- **TS-1　商用停電**
- **TS-2　商用瞬低**
- **TS-3　母線短絡**
- **TS-4　電動機始動**

過渡安定度解析 - ETAP による Industrial System Model の解析例

Table 35.4 Summary of transient-stability analysis for an industrial system.

Scenario	Event/Action/Results/Countermeasures
Industrial plant islanding from power grid	
TS-1	Event 1: Islanding the system from power grid = > Action: open CB-66 kV at 0.1 sec Results: Generator speed falls, and mechanical power reaches up to 50 MW (generator rated power) = > Generator trips, and the system will collapse. 
TS-1A	*Countermeasure* *Load shed (trip L-T3 [30MVA] after 0.2 sec from Event 1)* Event 1: Islanding the system from power grid = > Action: open CB-66 kV at 0.1 sec Event 2: Load shedding after 0.2 sec from Event 1 (trip L-T3, 30 MVA) = > Action: open *CB-T1-3* at 0.3 sec Results: Both generator speed and mechanical power returned to stable conditions. 

TS-1 商用停電

TS-2 商用瞬低

TS-3 母線短絡

TS-4 電動機始動

TS-1

Event 1:

- 商用停電

Action 1:

- Open CB-66kV at 0.1sec.

Results:

- 発電機速度喪失
- 機械出力飽和

TS-1A

Event 1:

- 商用停電

Action 1:

- Open CB-66kV at 0.1sec.

Event 2:

- 負荷選択遮断 (50MW)

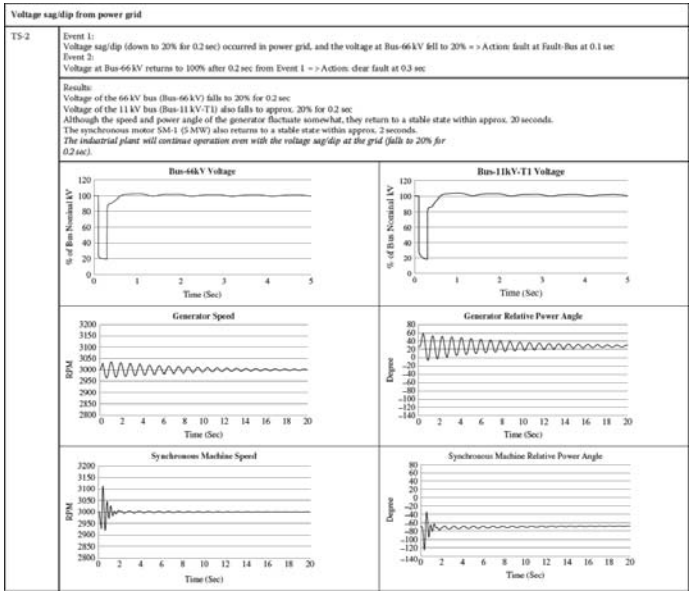
Action 2:

- Open CB-T1-3 at 0.3sec.

Results:

- 発電機速度回復
- 機械出力回復

過渡安定度解析 - ETAP による Industrial System Model の解析例



TS-1 商用停電

TS-2 商用瞬低

TS-3 母線短絡

TS-4 電動機始動

TS-2

Event 1:

- 商用瞬低

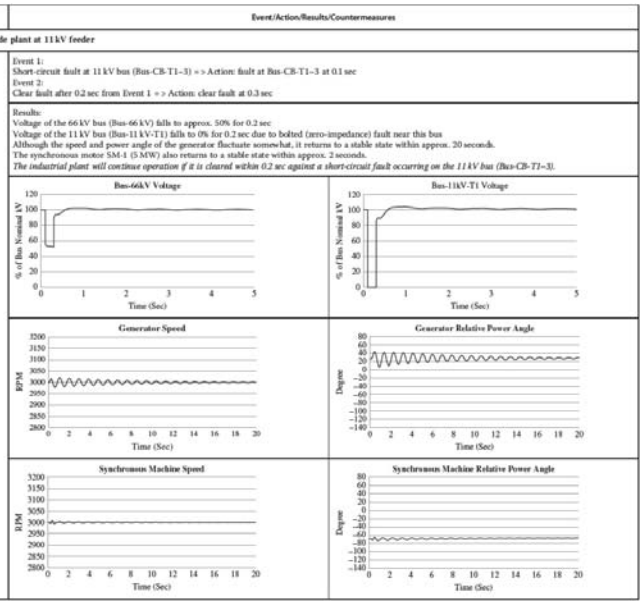
Action 1:

- 66kV受電母線電圧が、2秒間20%に低下

Results:

- 66kV母線電圧 => 回復
- 11kV母線電圧 => 回復
- 発電機速度 => 回復
- 発電機位相 => 回復
- 同期電動機速度 => 回復
- 同期電動機位相 => 回復

過渡安定度解析 - ETAP による Industrial System Model の解析例

Scenario	Event/Action/Results/Countermeasures
Fault inside plant at 11 kV feeder	
TS-3	Event 1: Short-circuit fault at 11 kV bus (Bus-CB-T1–3) = > Action: fault at Bus-CB-T1–3 at 0.1 sec Event 2: Clear fault after 0.2 sec from Event 1 = > Action: clear fault at 0.3 sec Results: Voltage of the 66 kV bus (Bus-66 kV) falls to approx. 50% for 0.2 sec Voltage of the 11 kV bus (Bus-11 kV-T1) falls to 0% for 0.2 sec due to bolted (zero-impedance) fault near this bus Although the speed and power angle of the generator fluctuate somewhat, it returns to a stable state within approx. 20 seconds. The synchronous motor SM-1 (5 MW) also returns to a stable state within approx. 2 seconds. *The industrial plant will continue operation if it is cleared within 0.2 sec against a short-circuit fault occurring on the 11 kV bus (Bus-CB-T1–3).* 

TS-1 商用停電

TS-2 商用瞬低

TS-3 母線短絡

TS-4 電動機始動

TS-3

Event 1:

- 11kV母線短絡

Action 1:

- 母線 Bus-CB-T1-3 で3相短絡事故, at 0.1sec.

Event 2:

- 0.2秒後に事故解除

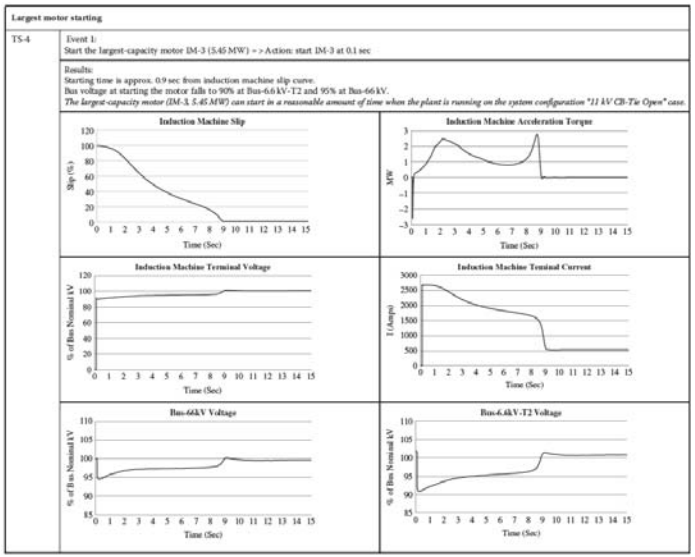
Action 2:

- 事故解除, at 0.3sec.

Results:

- 66kV母線電圧 => 回復
- 11kV母線電圧 => 回復
- 発電機速度 => 回復
- 発電機位相 => 回復
- 同期電動機速度 => 回復
- 同期電動機位相 => 回復

過渡安定度解析 - ETAP による Industrial System Model の解析例



TS-1 商用停電

TS-2 商用瞬低

TS-3 母線短絡

TS-4 電動機始動

TS-4

Event 1:

- IM-3 (5.45MW) 始動

Action 1:

- Start IM-3, at 0.1sec.

Results:

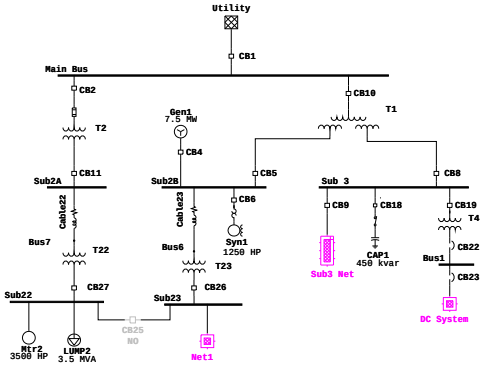
- 電動機すべり => 9sec.
- 加速トルク => 回復
- 電動機端子電圧 => 90%
- 電動機電流 => 回復
- 66kV 母線電圧 => 95%
- 6.6kV 母線電圧 => 92%

ETAP Workshop E100JP

過渡安定度解析

事故・系統動揺

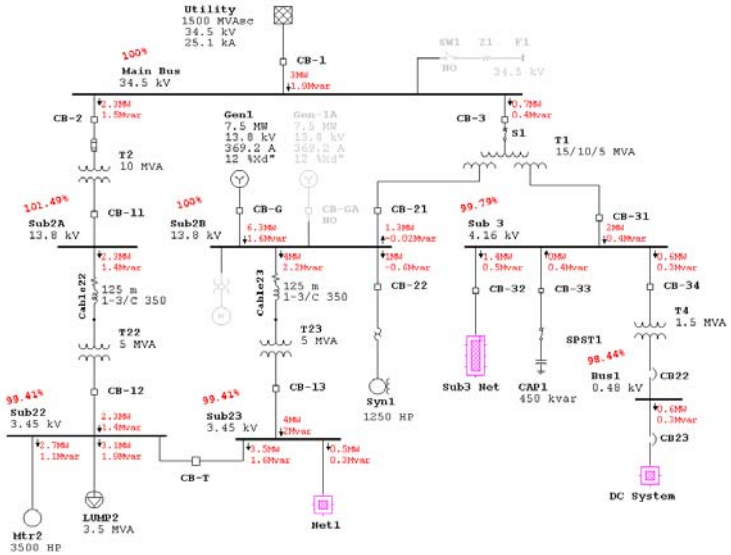
- 停電
- 瞬低
- 短絡事故
- 系統切換
- 発電機停止
- 大容量電動機始動



設定項目

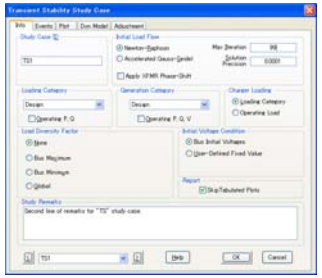
- イベントおよびアクションの設定
- 保護継電器動作によるアクションの設定
- 瞬時電圧低下現象のモデリング
- 発電機のモデリング
- 誘導電動機のモデリング
- スタディケースの設定

Sample Project　　初期潮流のチューニング



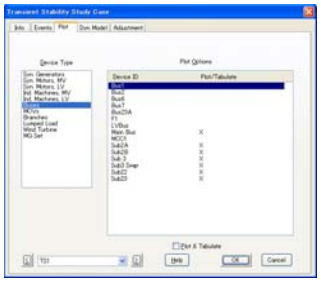
Study Case の設定

1. 初期潮流計算の設定

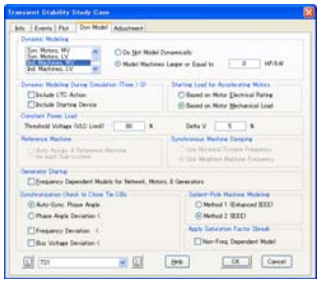


2. イベント & アクションの設定

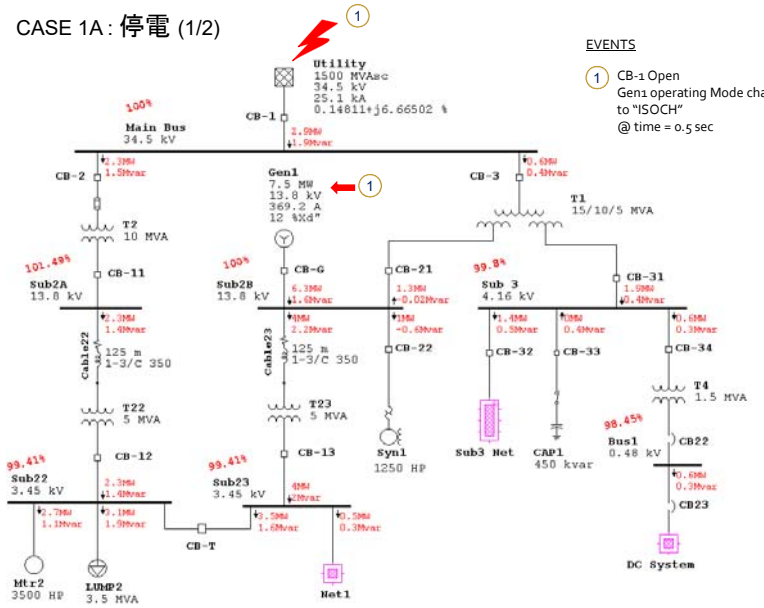
3. Plot （グラフ）の設定



4. ダイナミックモデルの設定



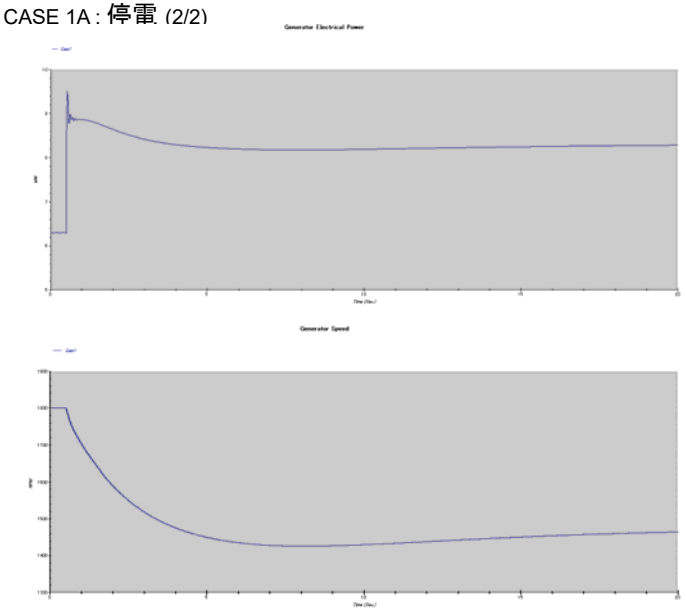
CASE 1A : 停電 (1/2)



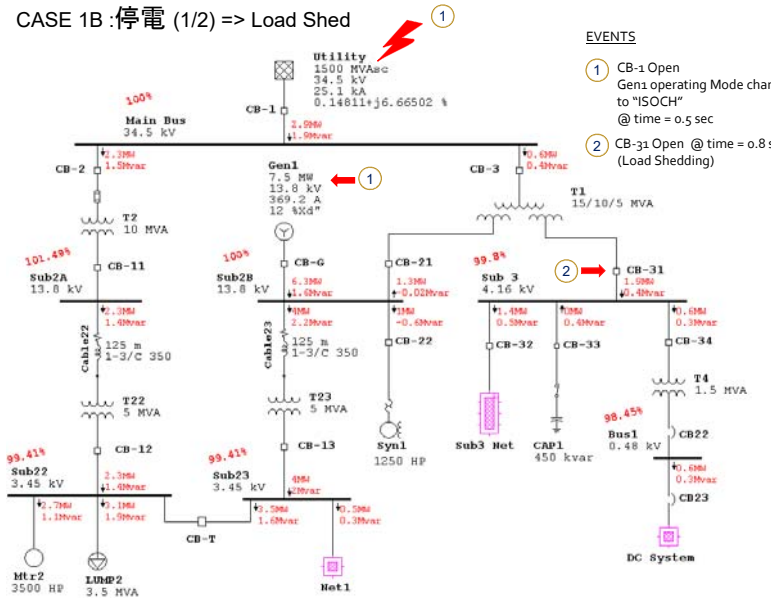
EVENTS

1 CB-1 Open
Gen1 operating Mode change
to "ISOCH"
@ time = 0.5 sec

CASE 1A : 停電 (2/2)



CASE 1B :停電 (1/2) => Load Shed

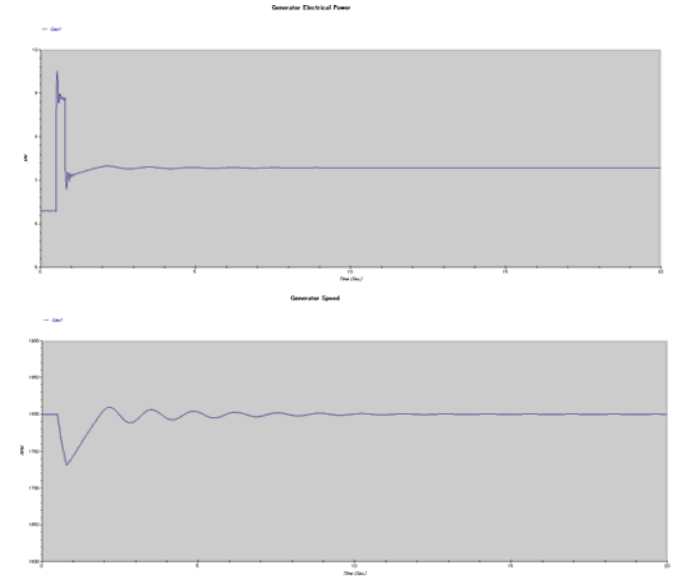


EVENTS

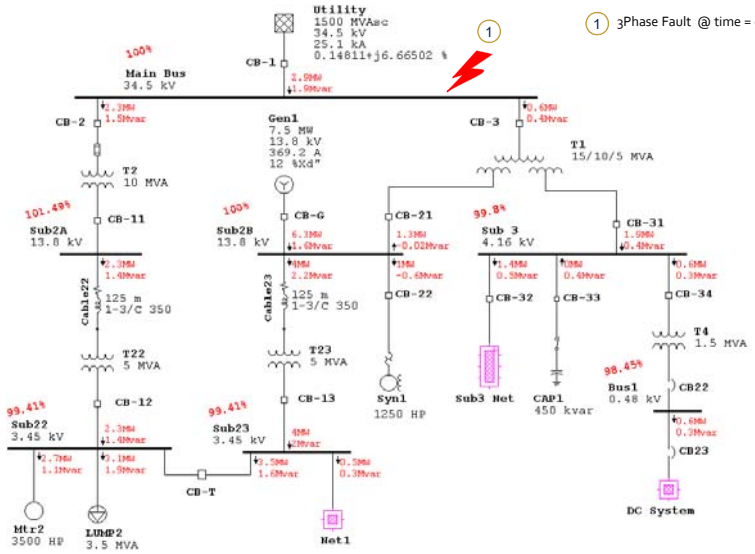
1 CB-1 Open
Gen1 operating Mode change
to "ISOCH"
@ time = 0.5 sec

2 CB-31 Open @ time = 0.8 sec
(Load Shedding)

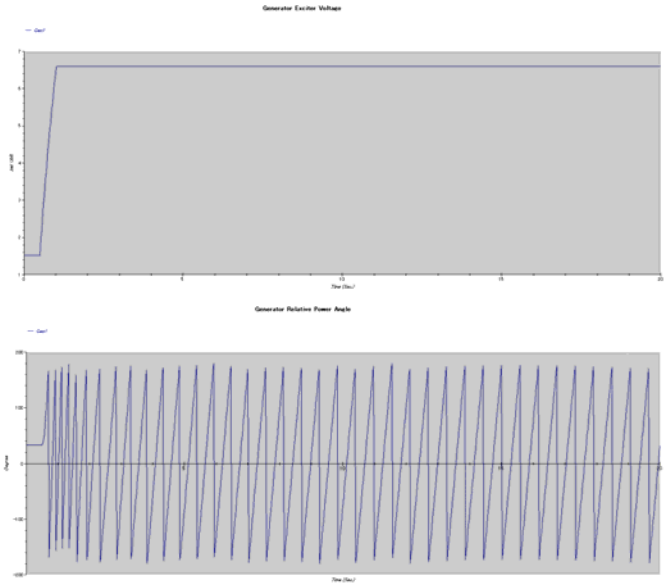
CASE 1B : 停電 (2/2) => Load Shed



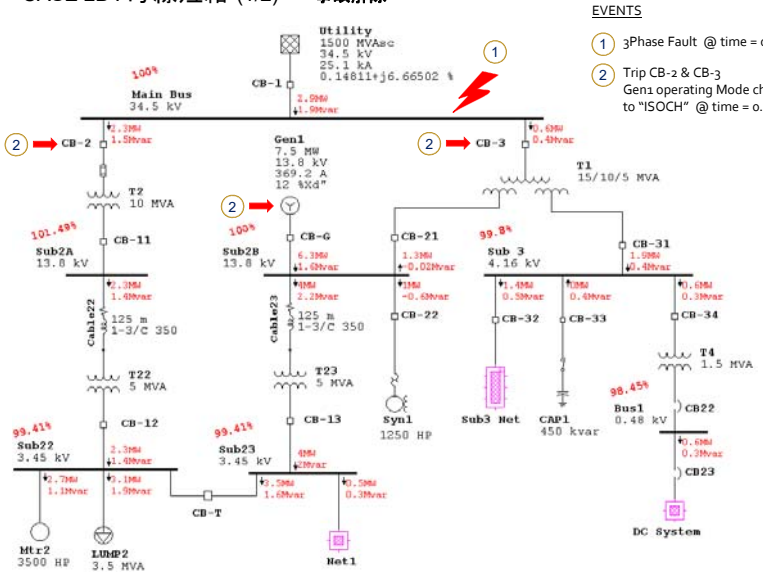
CASE 2A : 母線短絡 (1/2) => **事故継続**



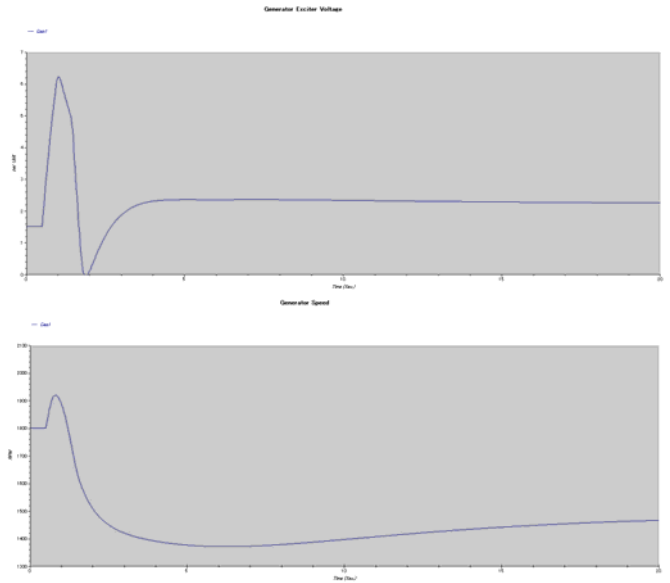
CASE 2A : 母線短絡 (2/2) => **事故継続**



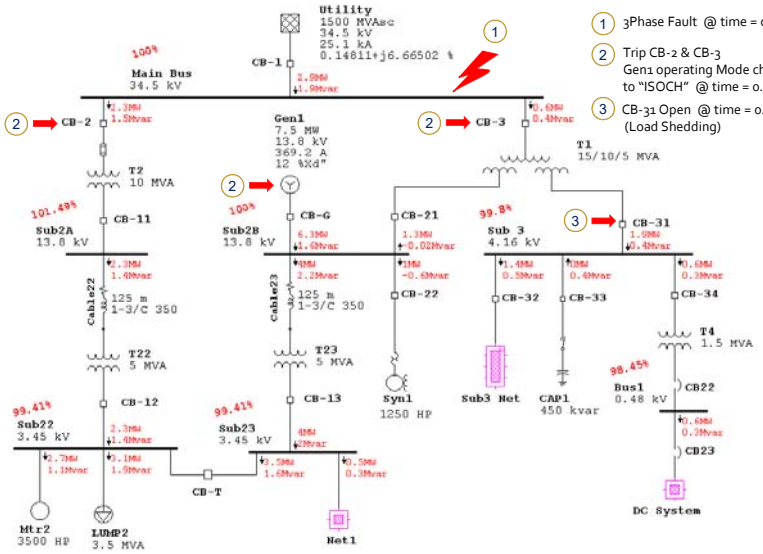
CASE 2B : 母線短絡 (1/2) => **事故解除**



CASE 2B : 母線短絡 (2/2) => **事故解除**



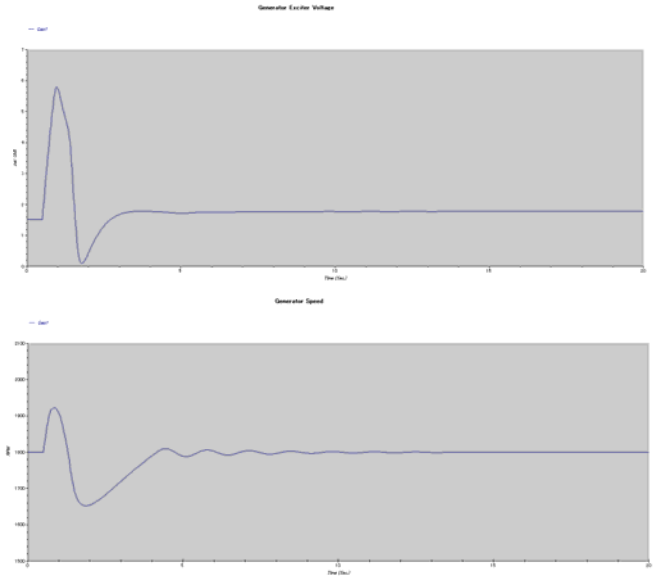
CASE 2C : 母線短絡 (1/2) => Load Shedding



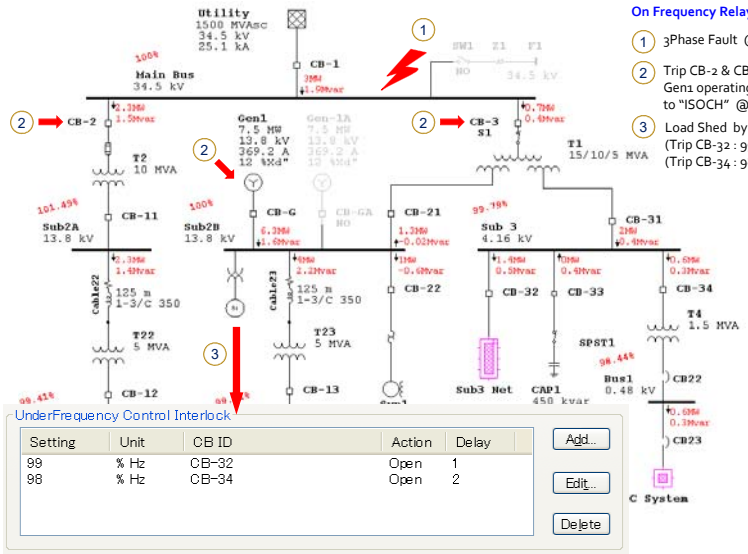
EVENTS

1. 3Phase Fault @ time = 0.5 sec
2. Trip CB-2 & CB-3
   Gen1 operating Mode change
   to "ISOCH" @ time = 0.7 sec
3. CB-31 Open @ time = 0.8 sec
   (Load Shedding)

CASE 2C : 母線短絡 (2/2) => Load Shedding



CASE 2D : 母線短絡 (1/2) => Load Shed by Freq. Relay

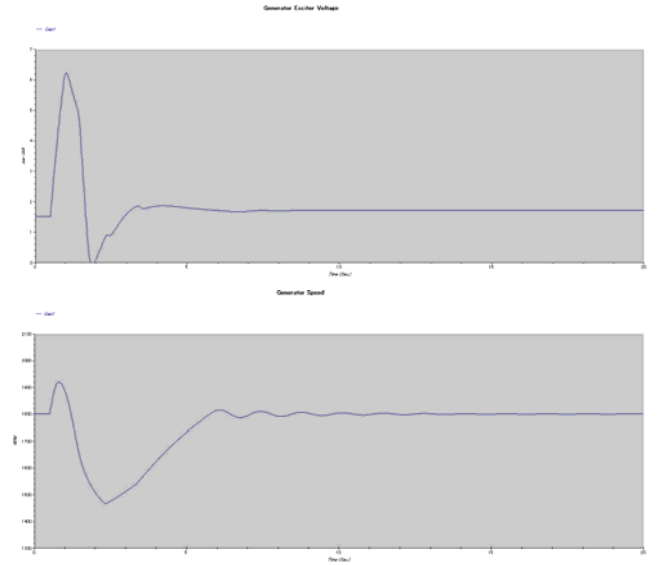


EVENTS

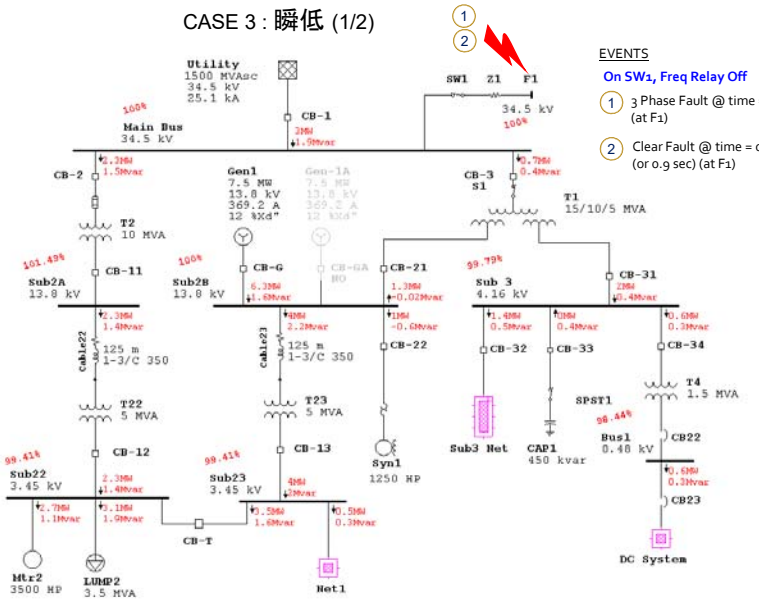
On Frequency Relay

1. 3Phase Fault @ time = 0.5 sec
2. Trip CB-2 & CB-3
   Gen1 operating Mode change
   to "ISOCH" @ time = 0.7 sec
3. Load Shed by Freq. Relay
   (Trip CB-32 : 99%, 1 sec)
   (Trip CB-34 : 98%, 2 sec)

CASE 2D : 母線短絡 (2/2) => Load Shed by Freq. Relay



CASE 3 : 瞬低 (1/2)

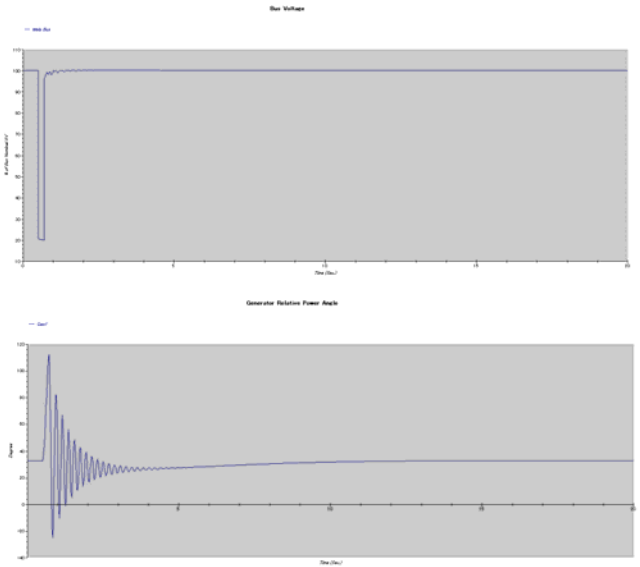


EVENTS

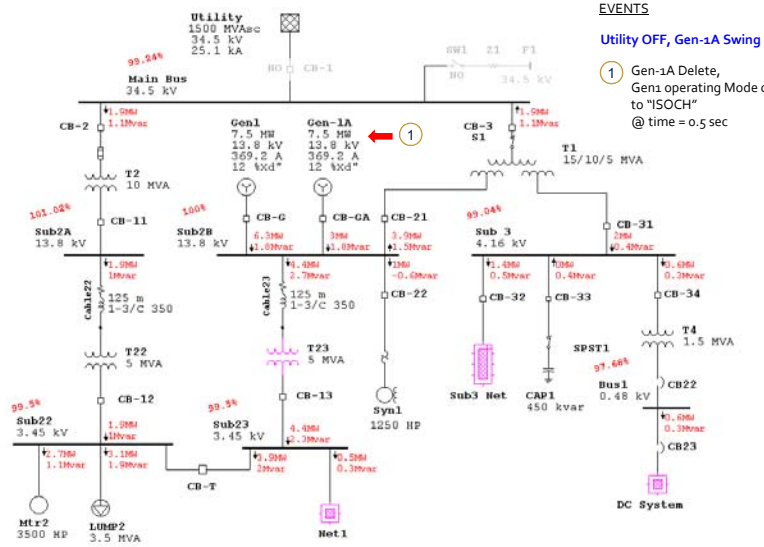
On SW1, Freq Relay Off

1. 3 Phase Fault @ time = 0.5 sec (at F1)
2. Clear Fault @ time = 0.7 sec (or 0.9 sec) (at F1)

CASE 3 : 瞬低 (2/2)



CASE 4A : 発電機停止 (1/2)

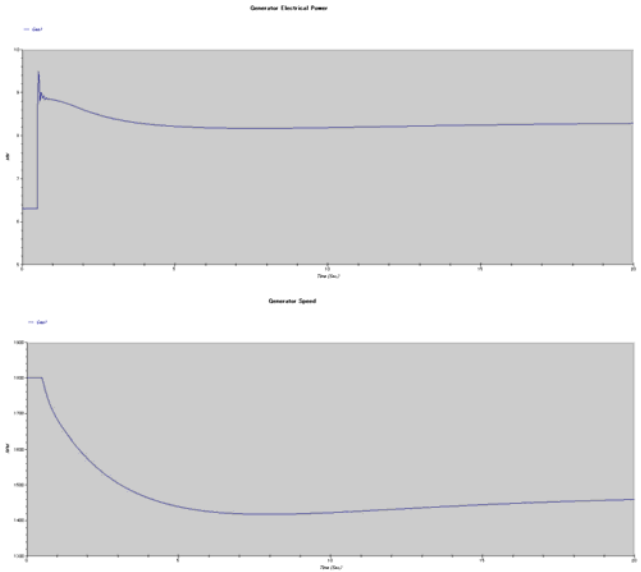


EVENTS

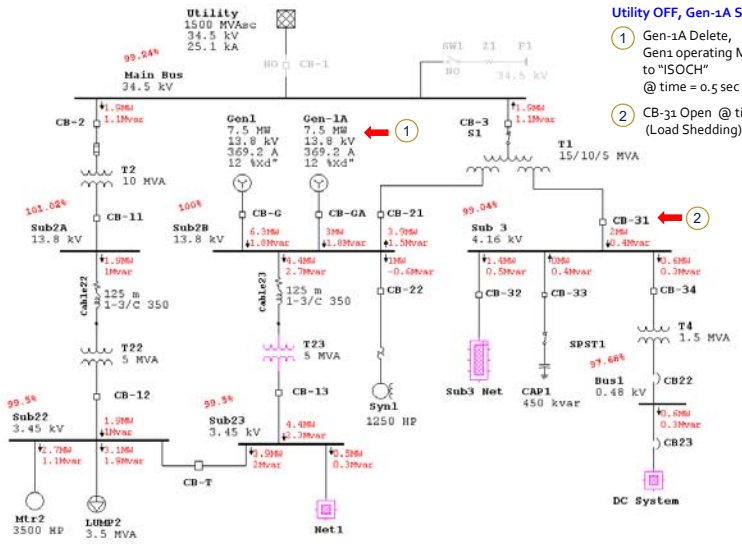
Utility OFF, Gen-1A Swing

1. Gen-1A Delete, Gen1 operating Mode change to "ISOCH" @ time = 0.5 sec

CASE 4A : 発電機停止 (2/2)



CASE 4B : 発電機停止 (1/2) => Load Shedding

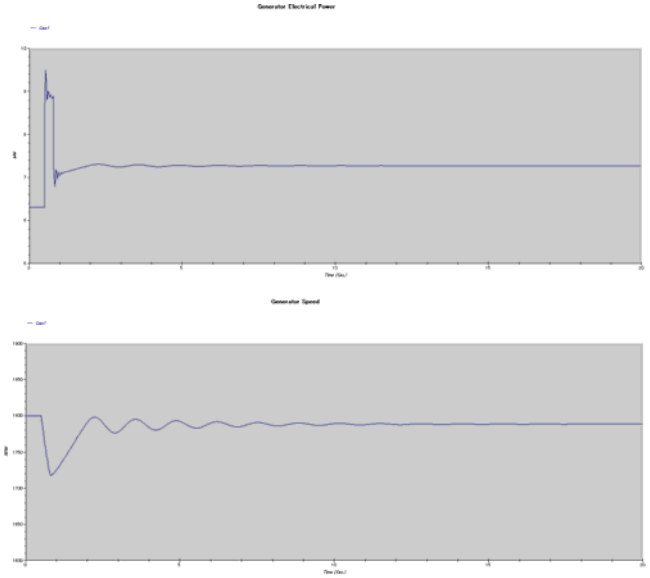


EVENTS

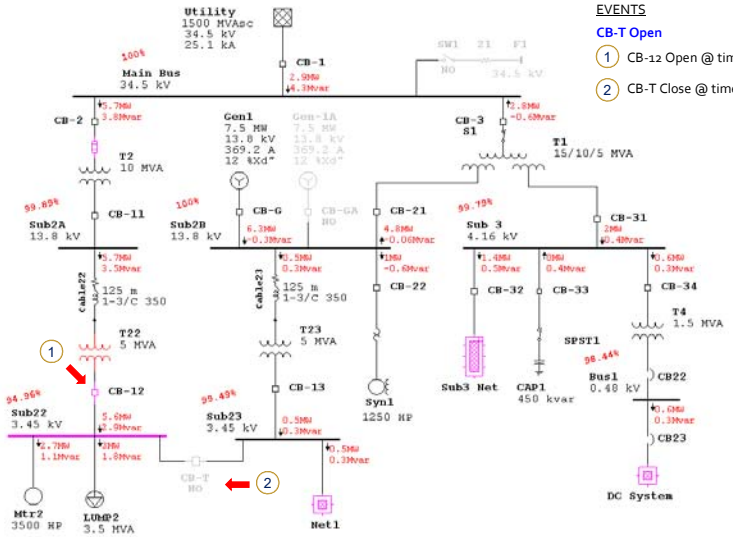
Utility OFF, Gen-1A Swing

1. Gen-1A Delete, Gen1 operating Mode change to "ISOCH" @ time = 0.5 sec
2. CB-31 Open @ time = 0.8 sec (Load Shedding)

CASE 4B : 発電機停止 (2/2) => Load Shedding



CASE 5 : 系統切換 (1/2)

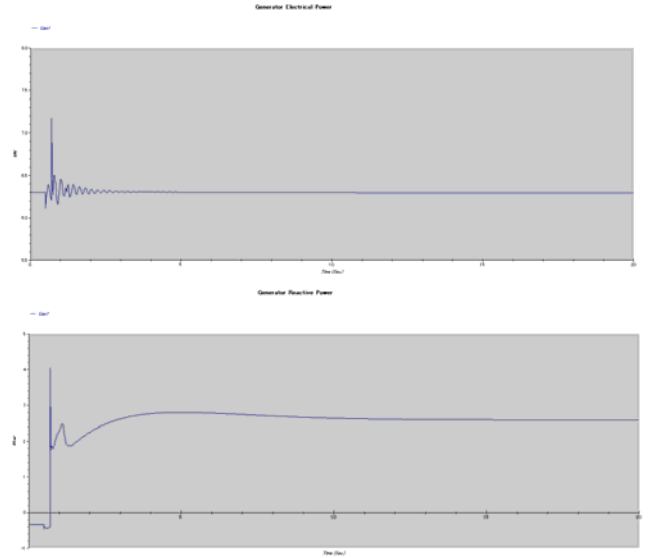


EVENTS

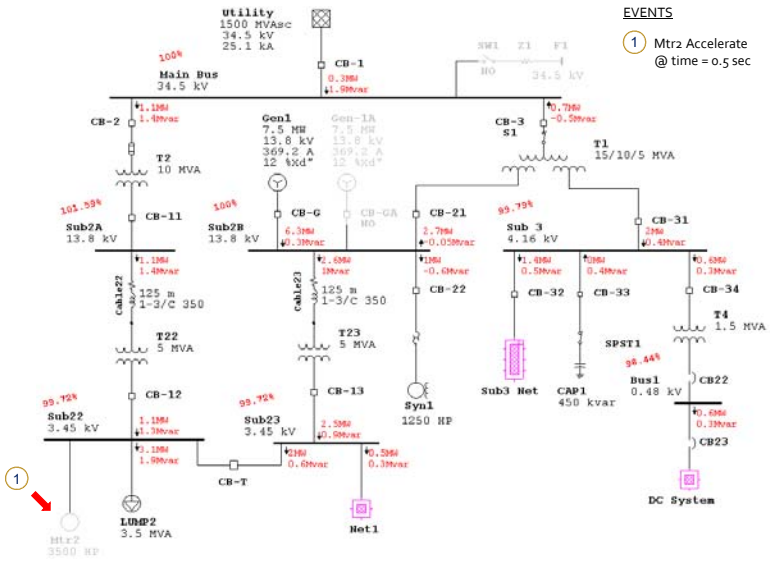
CB-T Open

1. CB-12 Open @ time = 0.5 sec
2. CB-T Close @ time = 0.7 sec

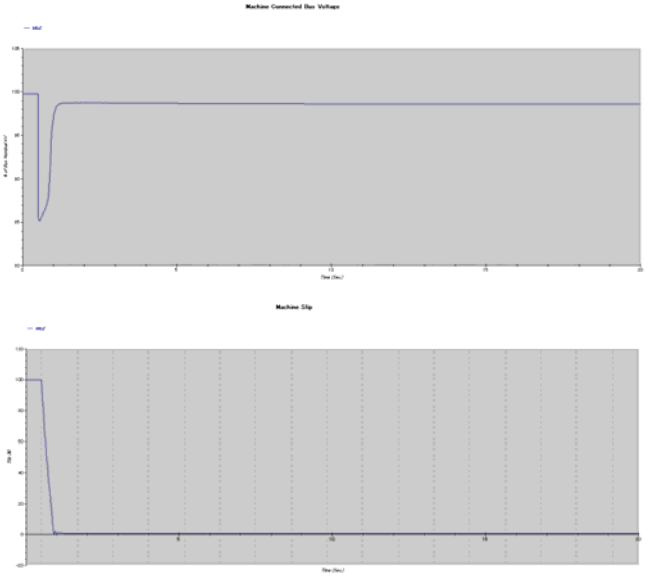
CASE 5 : 系統切換 (2/2)



CASE 6 : 大容量電動機始動 (1/2)



CASE 6 : 大容量電動機始動 (2/2)



アクション の設定 (1/2)

Device Type	Actions	Setting 1	Setting 2
Bus	3 Phase Fault / Clear Fault/	-	-
	LG Fault		
Cable	Fault / Clear Fault	% of total length	-
Line	Fault / Clear Fault	% of total length	-
Impedance	Fault / Clear Fault	% of total length	-
Circuit Breaker	Open / Close	-	-
SPST Switch	Open / Close	-	-
Contactor	Open / Close	-	-
Fuse	Trip	-	-
Generator	Ref. Machine	-	-
	Droop	-	-
	Isoch	-	-
	Start	-	-
	Loss Excitation	-	-
	Generation Impact	% change in electrical power	-
	Generation Ramp	% change in electrical power	Time (sec) for % change
	Voltage Impact	% change in reference voltage	-
	Voltage Ramp	% change in reference voltage	Time (sec) for % change
	Delete	-	-
Utility	Ref. Machine	-	-
	Voltage Impact	% change in reference voltage	-
	Voltage Ramp	% change in reference voltage	Time (sec) for % change
	Delete	-	-

アクション の設定 (2/2)

Syn. Motor	Accel	-	-
	Load Impact	% change in loading	-
	Load Ramp	% change in loading	Time (sec) for % change
	Delete	-	-
Ind. Motor	Accel	-	-
	Load Impact	% change in loading	-
	Load Ramp	% change in loading	Time (sec) for % change
	Delete	-	-
Lumped Load	Load Impact	% change in loading	-
	Load Ramp	% change in loading	Time (sec) for % change
	Delete	-	-
MOV	Start	-	-
Wind Turbine	U-D Wind Disturbance		
	Wind Gust		
	Wind Ramp		
Wind Turbine (Zone)	U-D Wind Disturbance		
	Wind Gust		
	Wind Ramp		
None	Load Flow (no action, print load flow at the event time)	-	-