Integration of Stochastic Generation in Power System

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Electrical Engineering, NERIST, 2015

Outline

- Introduction
- Thesis aim and goal
- Approach/methodology
- Thesis outcomes and results
- Conclusion
- Future work
- Reference

Thesis Aim and Goal

- Model stochastic sources
- Characterise and classify stochastic network sources
- Build and simulate stochastic power systems
- Perform Stochastic load flow analysis
- Develop toolbox and programming support

Thesis Problem Statement

- Given a power network, *PS* with *N* nodes/ buses
- *G* deterministic sources, *S* stochastic sources and *L* loads with dependence structure *D*
- Perform stochastic load flow analysis and find
  - Power flow in each branch (active power P(MW), reactive power Q(MVAR)
  - Voltage at each node
  - Probability distribution of voltages and power flow

Approach

DETERMINISTIC LOAD FLOW

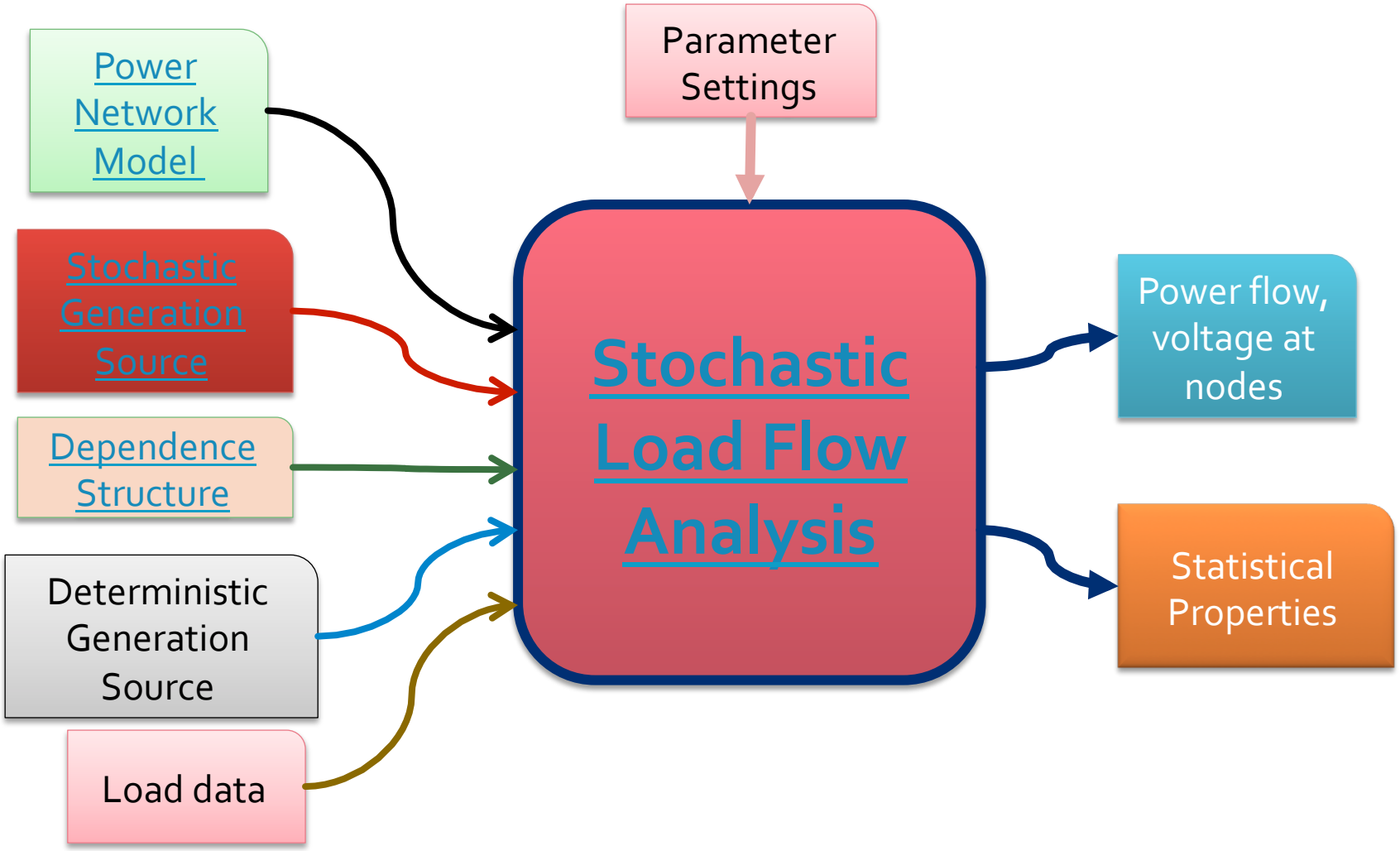
- **Steady-state analysis**
- **Inputs:**
  - Generation/PV, load/PQ & slack bus data, network model
- **Solver:**
  - linear system solvers
  - GS, NR, FD
- **Output:**
  - Power Flow, Voltage

STOCHASTIC LOAD FLOW

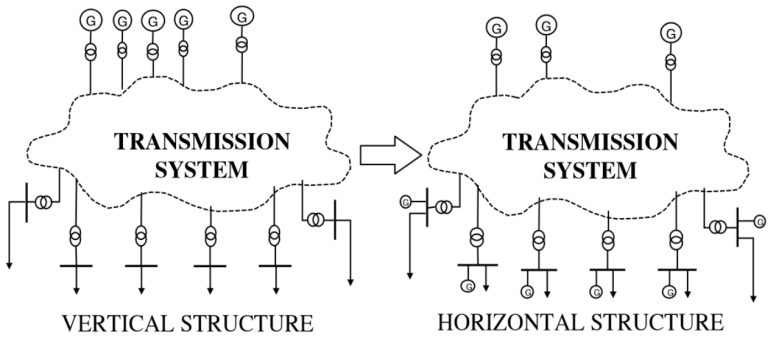
- **Steady-state uncertainty analysis**
- **Inputs:**
  - Generation/PV, load/PQ & slack bus data, network model, stochastic generation source
- **Solver:**
  - Monte-Carlo (Statistical) of DLF
  - Non-linear system statistical analysis
- **Output:**
  - Power Flow, Voltage
  - Pdf of power, voltage

[Ref. 3,4,6,7]

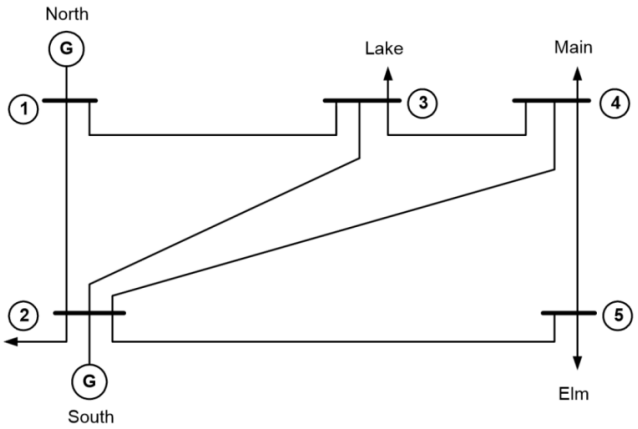
Approach


Power Network Model
Parameter Settings
Stochastic Generation Source
Stochastic Load Flow Analysis
Power flow, voltage at nodes
Dependence Structure
Deterministic Generation Source
Statistical Properties
Load data

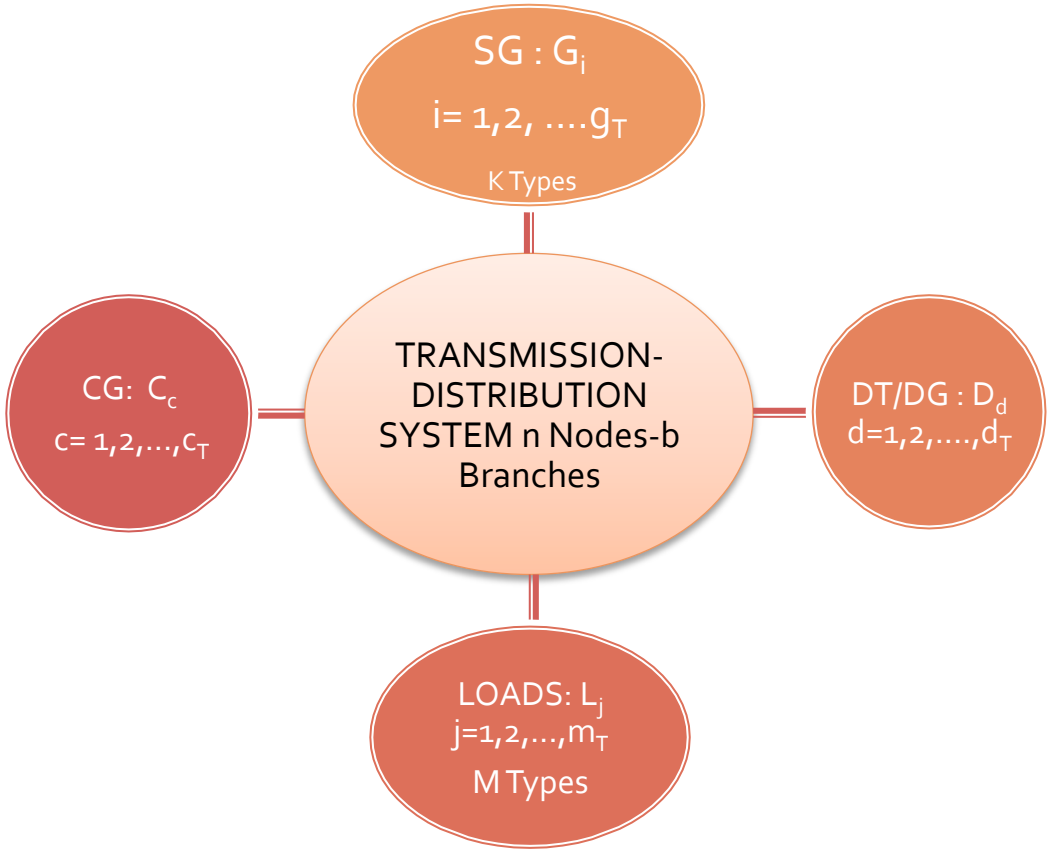
Power System Network Model



PS Network Type



Single line diagram representation



Power System Schematic Representation

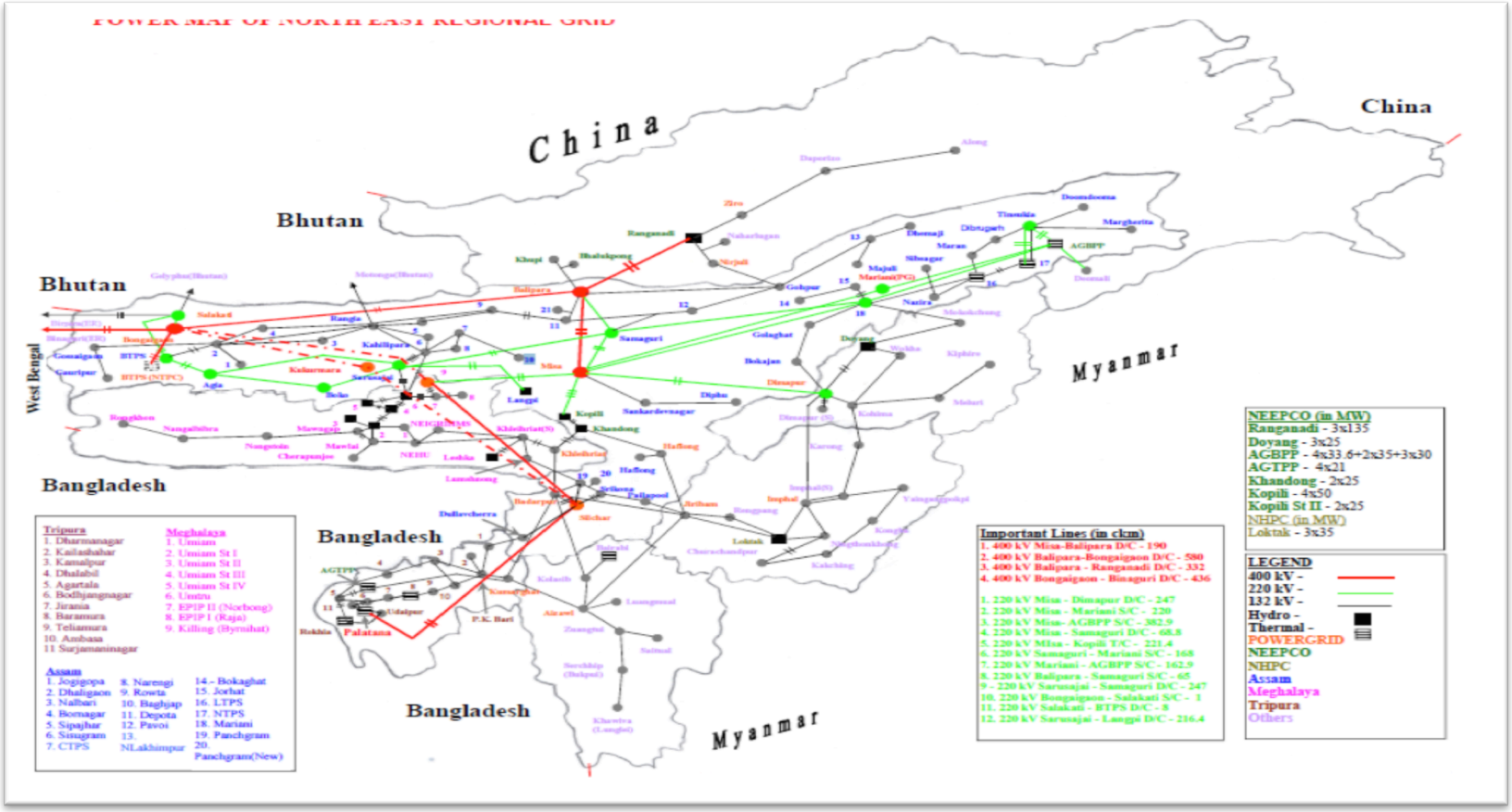
[Ref.2]

Analysis of NER Grid with Proposed Methodology

- Introduction to NER Grid
- NER Grid includes seven states: Arunachal Pradesh, Assam, Tripura, Manipur, Nagaland, Mizoram and Meghalaya
- Central Generating Companies : NHPC(105 MW),NEEPCO (1130 MW),OTPCL (726 MW)
- No of Bus: 143 of which 5 are 66 kV,114 are 132 kV, 18 are 220 kV and 6 are 400 kV bus
- No of Generation Plants: 7 in Assam, 6 in Meghalaya,4 in Tripura, 2 in Nagaland, and 1 in Manipur, 1 in Arunachal Pradesh and 1 in Mizoram
- Primary transmission voltage: 400 kV, 220 kV, 132 kV, 66 kV
- Transmission length: 66 km (66kV), 6445 km (132 kV), 2346 km (220 kV) and 1019 km (400 kV) , total length is 9876 km
- Bus is loaded to 80 % of their capacity

[Ref. 14]

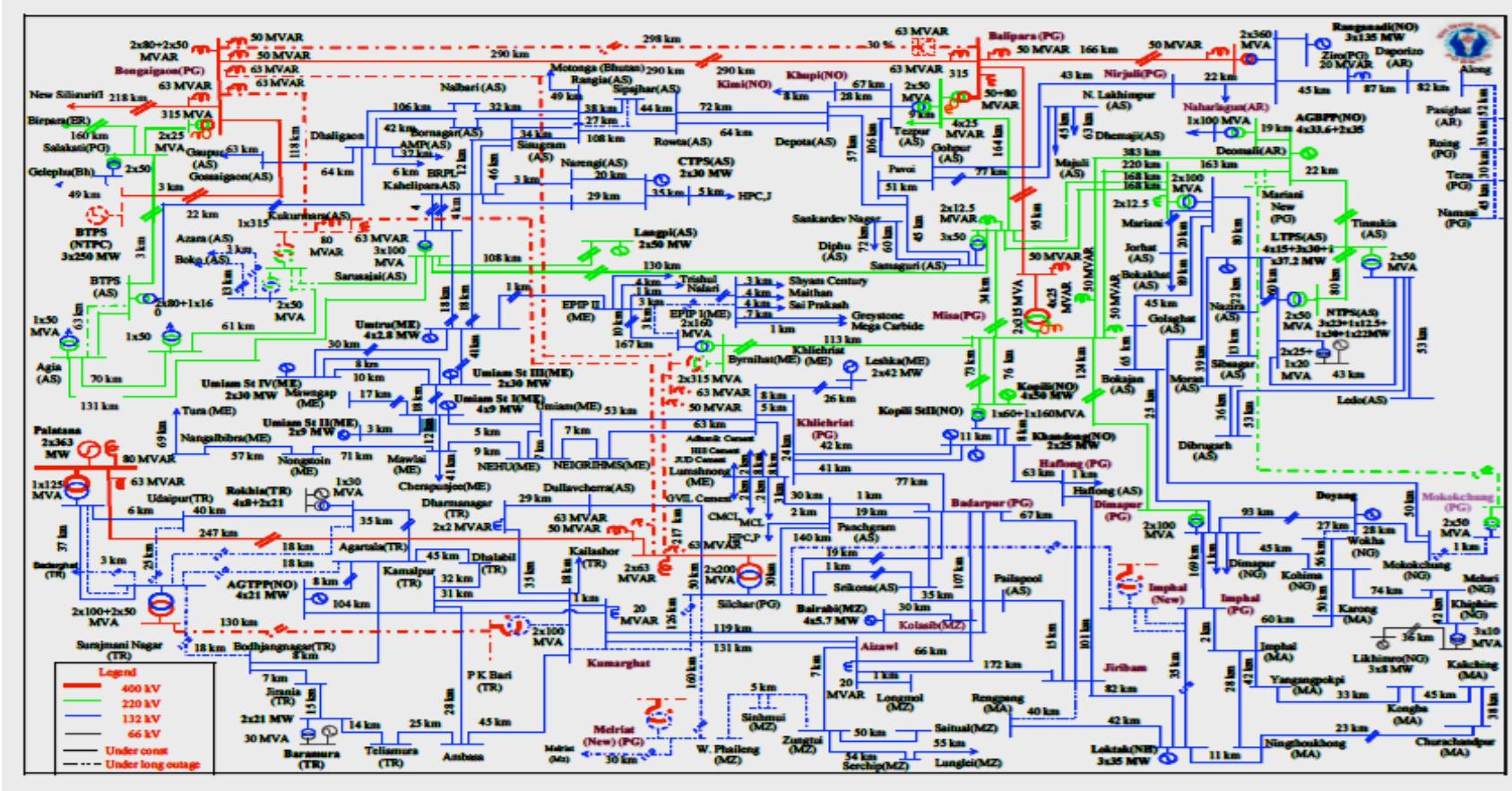
POWER MAP OF NORTH-EAST GRID



Power Map of NER Grid

Ref. 14

SINGLE LINA DIAGRAM OF NORTH-EAST GRID



Power Map of NER Grid

ref. 14

Implementation and Simulation Framework

- SimPowerSystems Software
- MATLAB Simulink is used for full power system network simulation. R 2013a
- Load Flow tool of Powergui , R 2013a : The Powergui block gives the following methods to solve a circuit:

- Continuous: solve a continuous circuit model

- Discrete: perform a discretization of the model for a solution at fixed time step. The sample time is specified by the Sample time parameter. Solver type such as Tustin, Backward Euler, od3 etc. are to discretize the electrical model

- Phasor: perform phasor simulation of the model, at the frequency specified by the Phasor frequency parameter

- Statistical toolbox, R 2013a :It is used to obtain statistical properties

Design Parameters for Modeling

- Transmission Line parameter: per unit positive and zero sequence resistance per km (R1,R0) , positive and zero sequence line inductance L1, L0 (H/km), and line charging capacitor C1, C0 (F/km), length of line
- Transformer model: MVA rating and voltage
- Synchronous Generator: MVA rating, frequency, voltage magnitude, angle, active power , reactive power depending on bus type
- Load Model : active (MW) and reactive (MVar)
- Bus: bus type (slack, generation and load)

SIMULINK MODEL OF NER GRID

TRIPURA

SOUTH ASSAM

MIZORAM

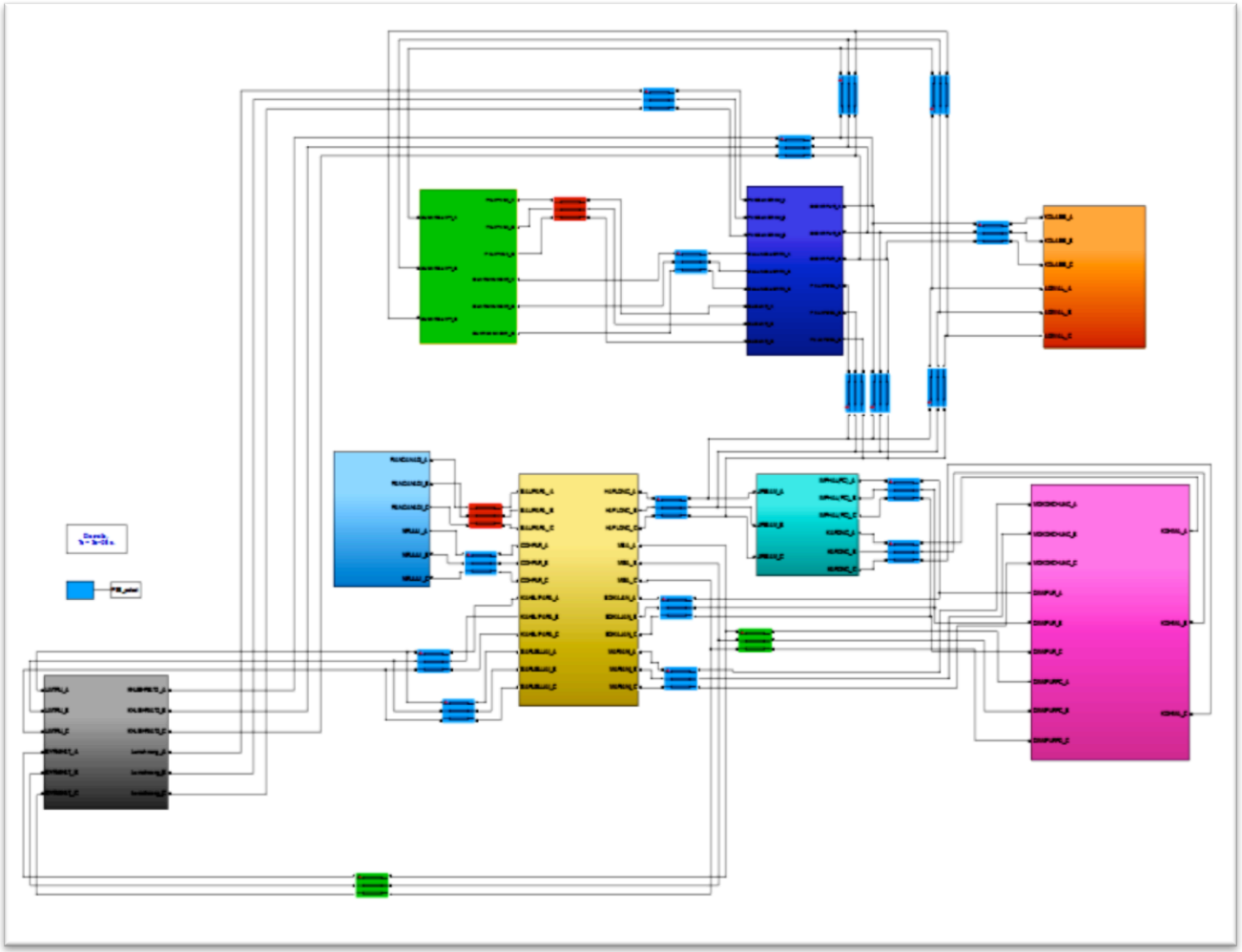
ARUNACHAL

ASSAM

MANIPUR

NAGALAND

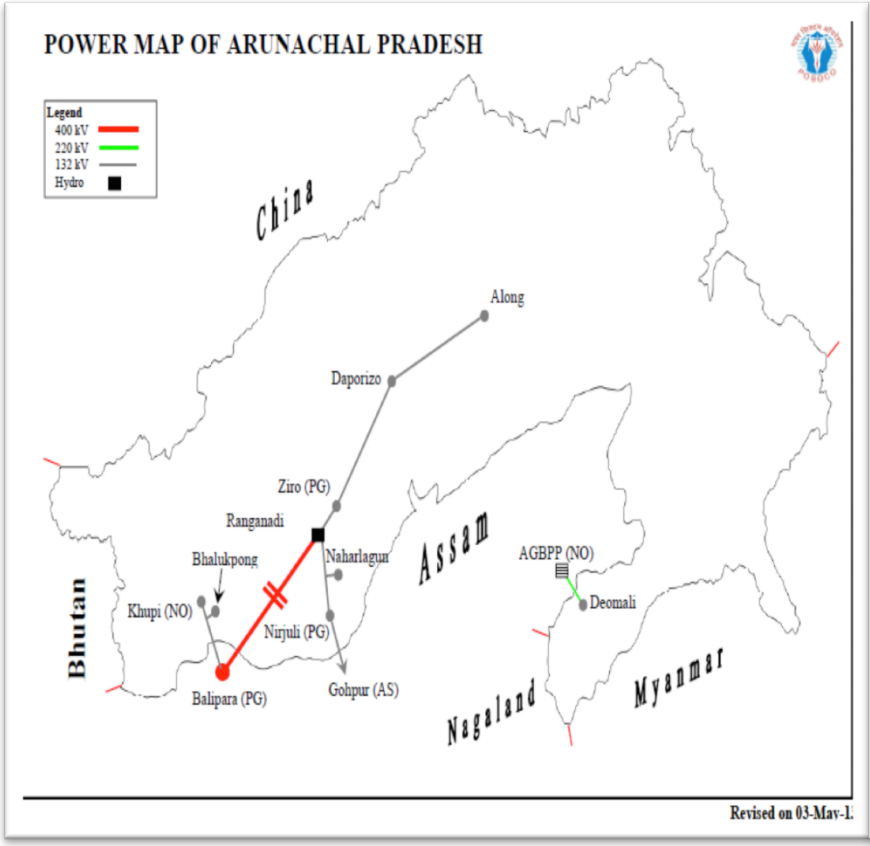
MEGHALAYA

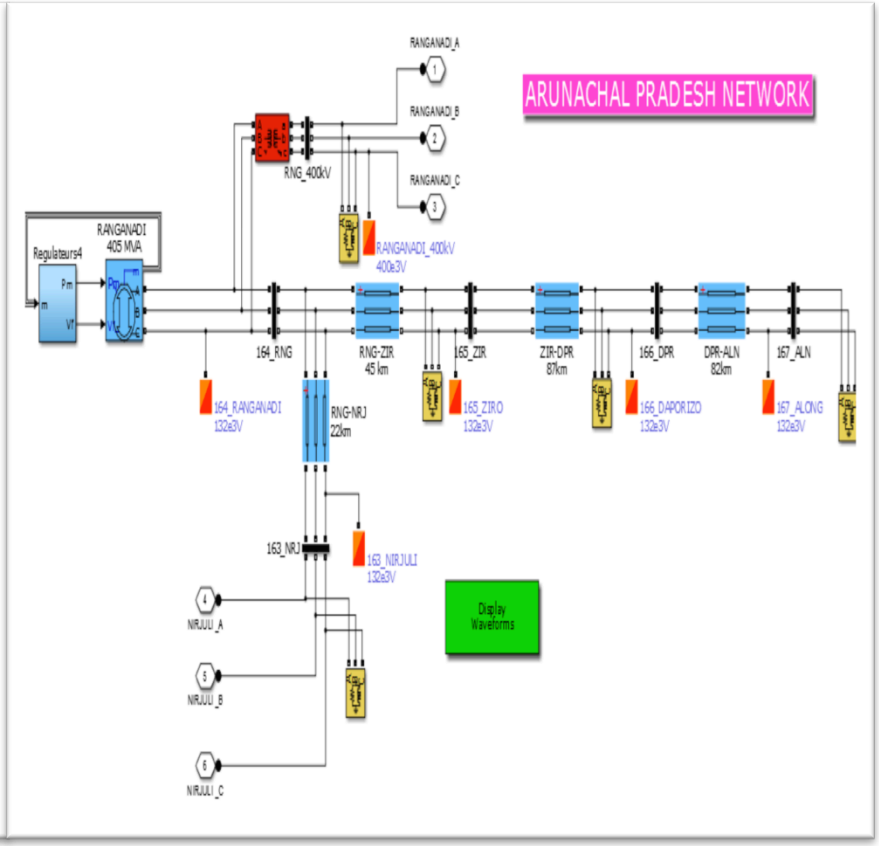


ARUNACHAL PRADESH NETWORK

POWER MAP OF ARUNACHAL PRADESH

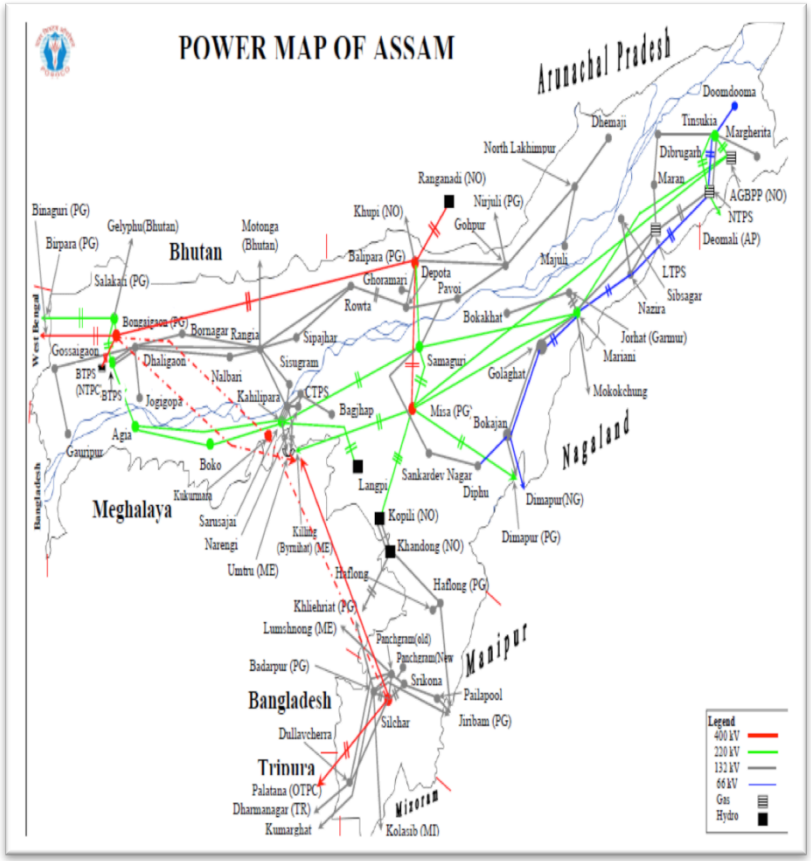
SIMULINK MODEL OF ARUNACHAL PRADESH



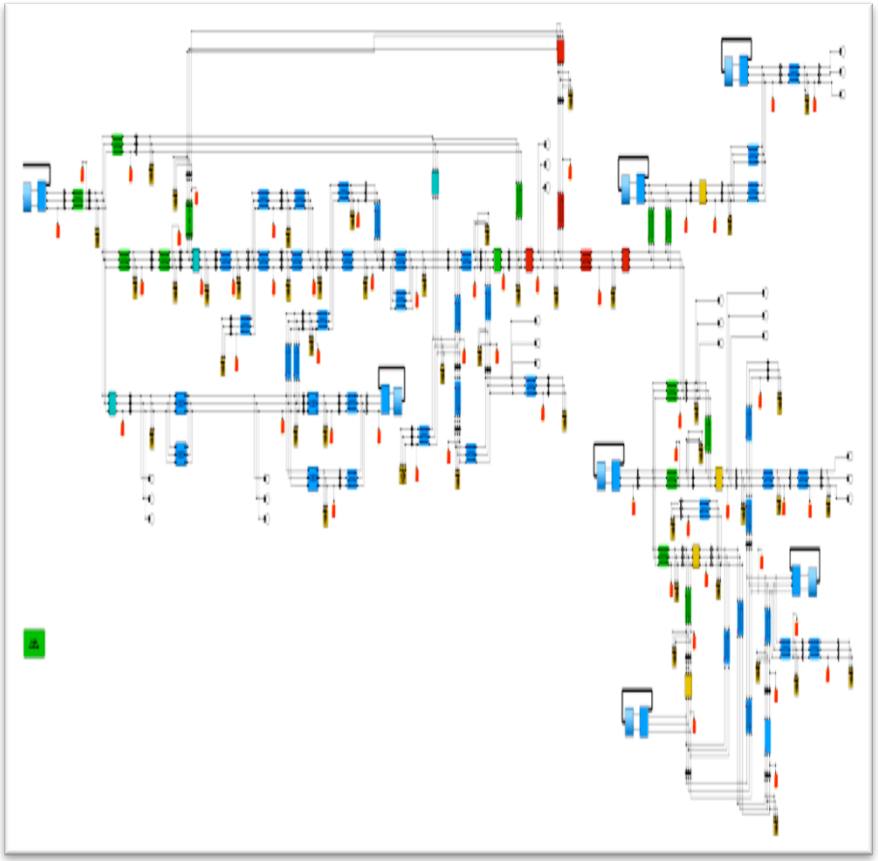


ASSAM NETWORK

POWER MAP OF ASSAM

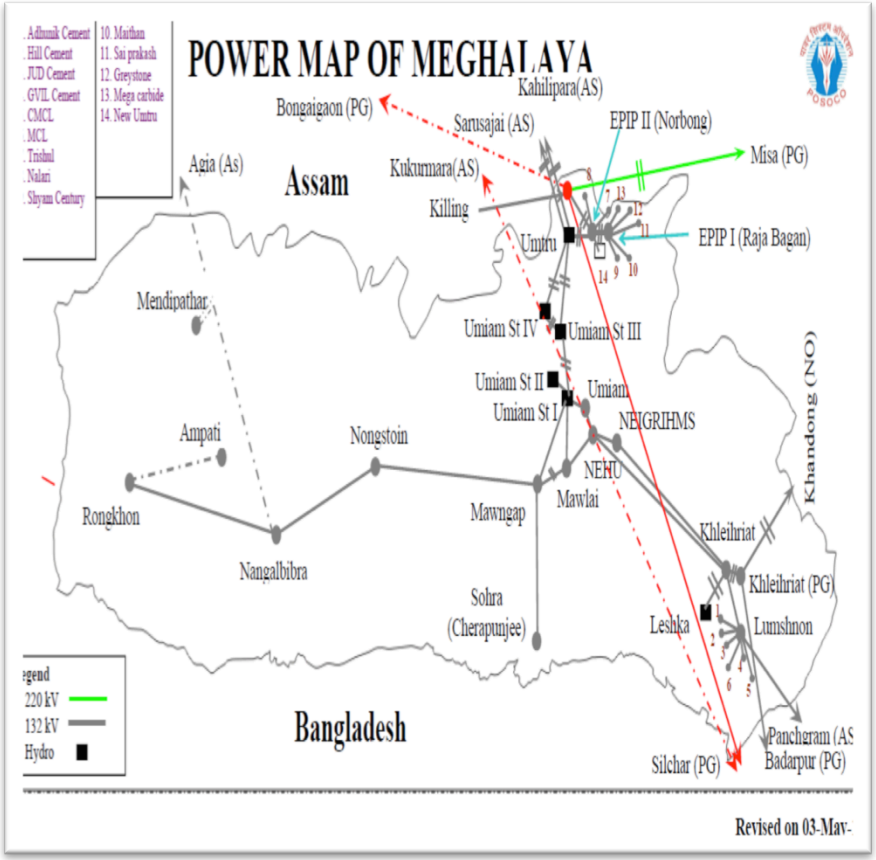


SIMULINK MODELOF ASSAM

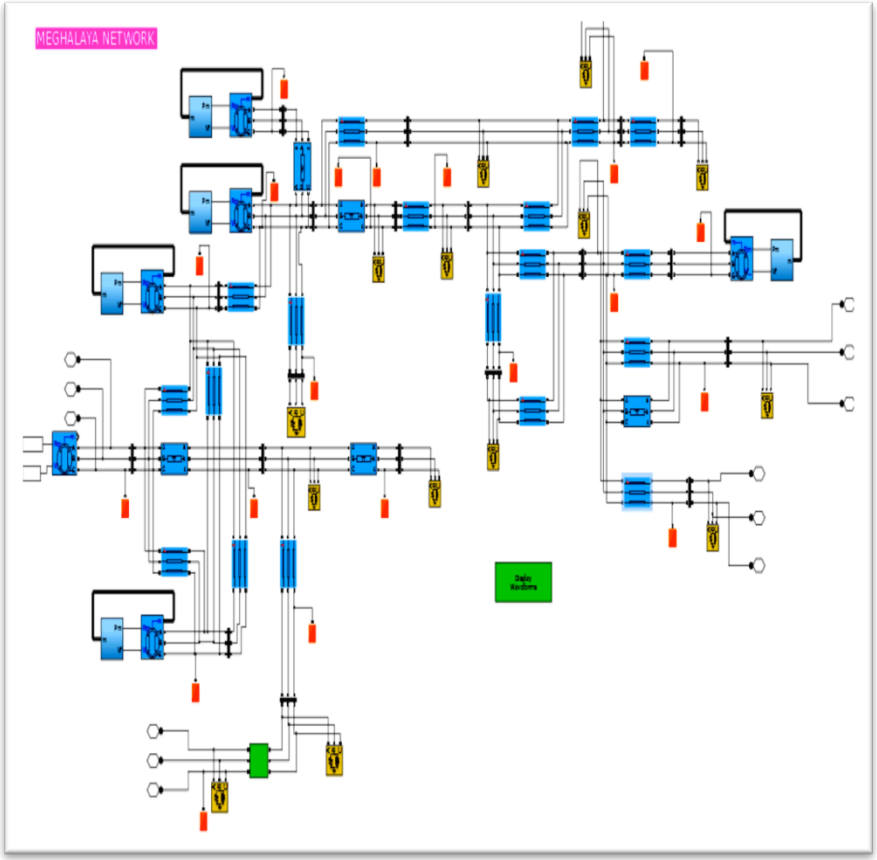


MEGHALAYA NETWORK

POWER MAP OF MEGHALAYA

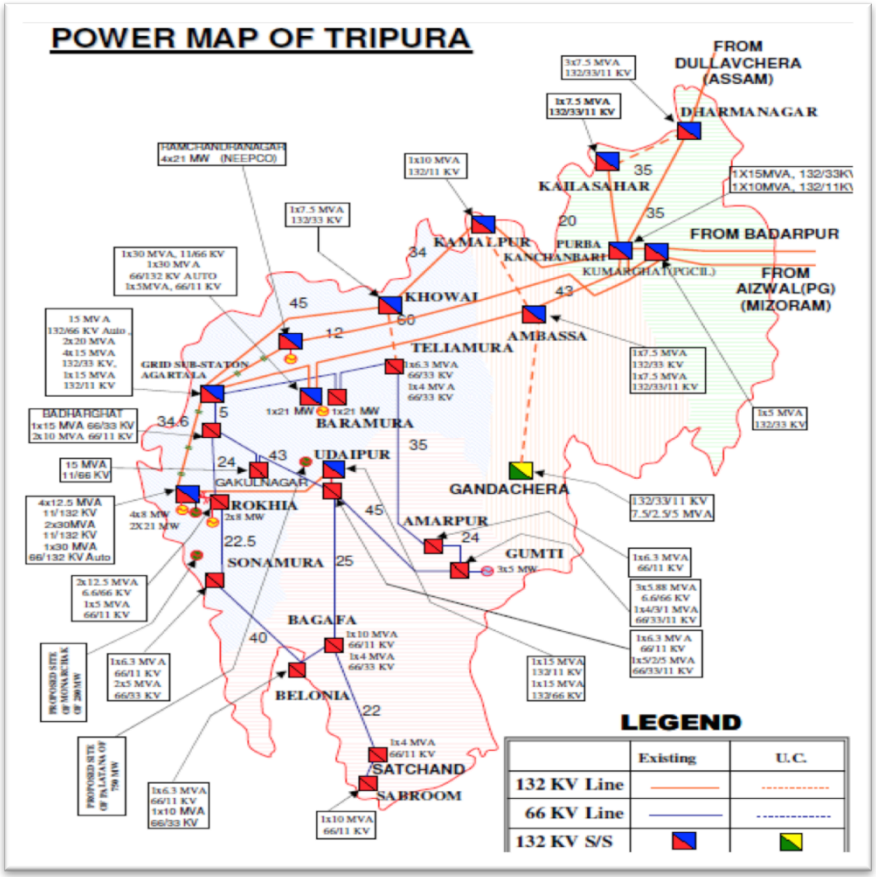


SIMULINK MODEL OF MEGHALAYA

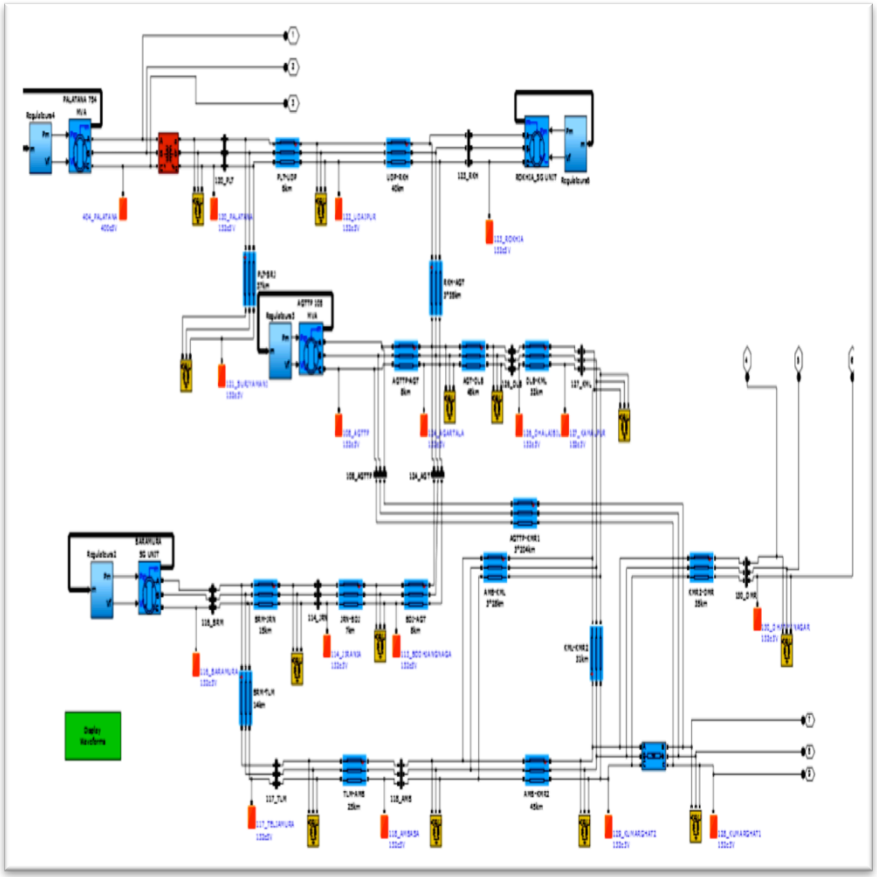


TRIPURA NETWORK

POWER MAP OF TRIPURA

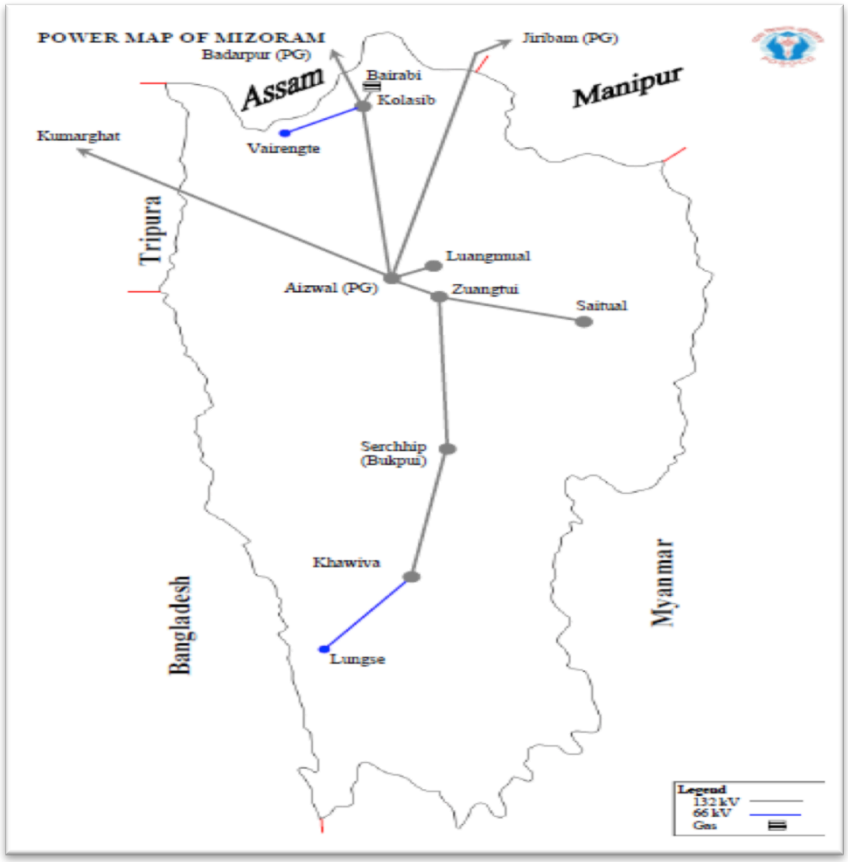


SIMULINK MODELOF TRIPURA

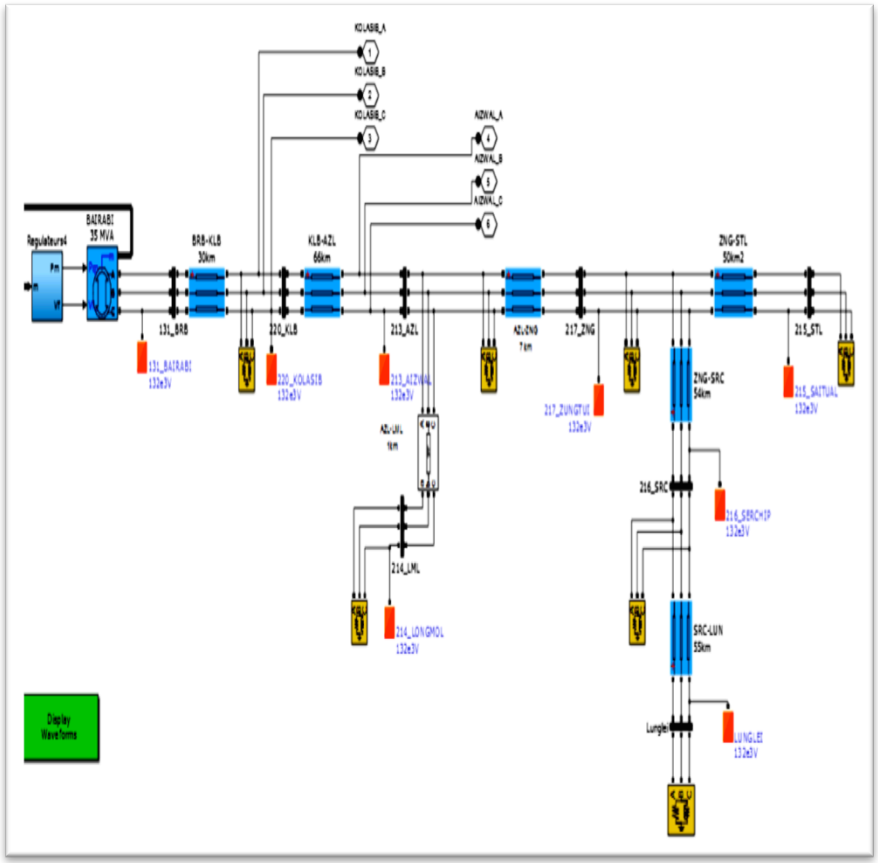


MIZORAM NETWORK

POWER MAP OF MIZORAM

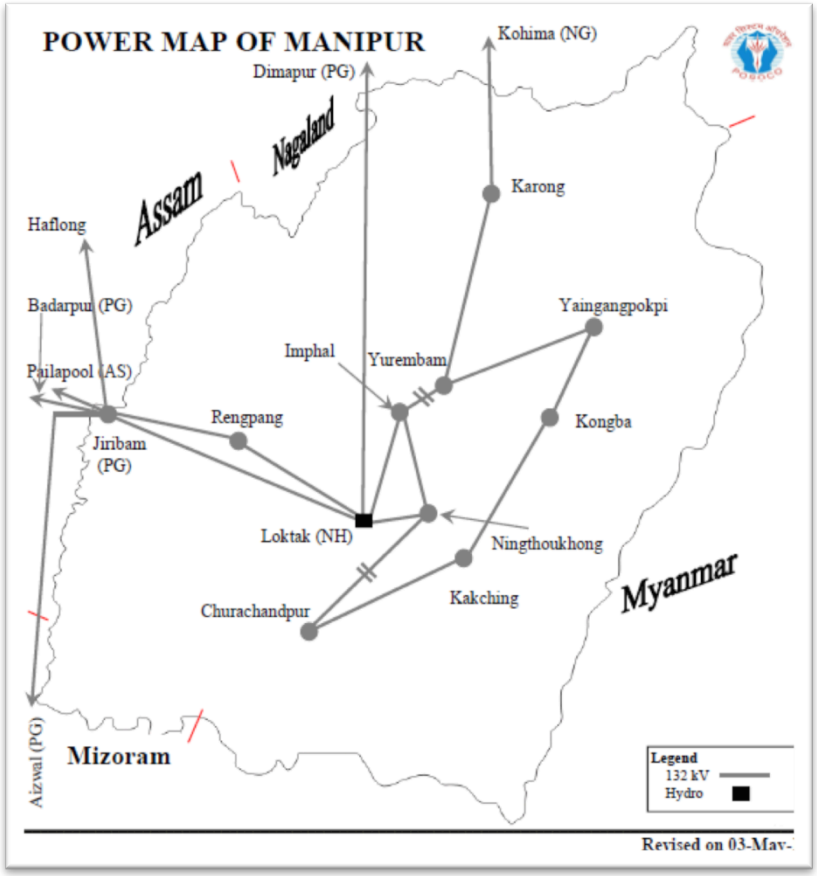


SIMULINK MODEL OF MIZORAM

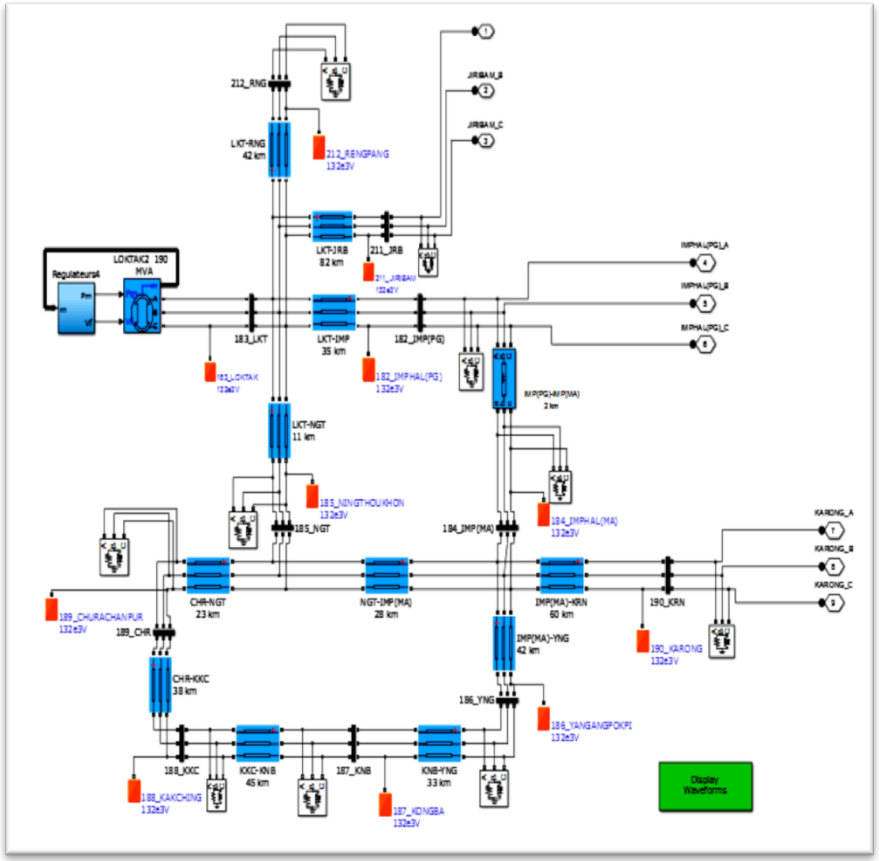


MANIPUR NETWORK

POWER MAP OF MANIPUR

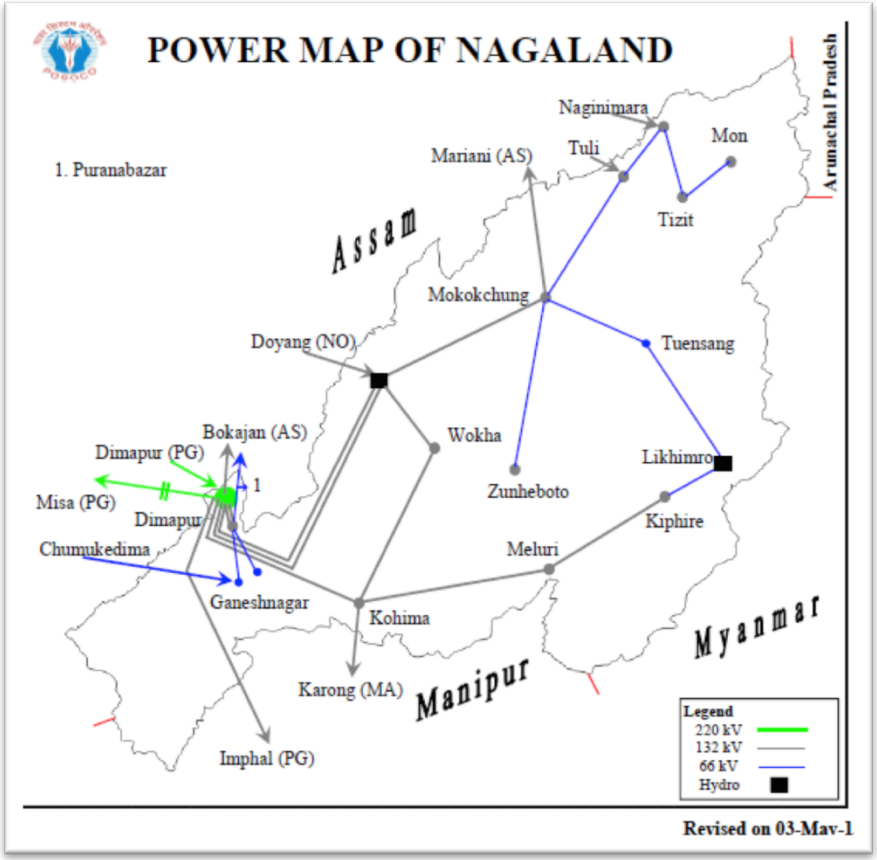


SIMULINK MODELOF MANIPUR

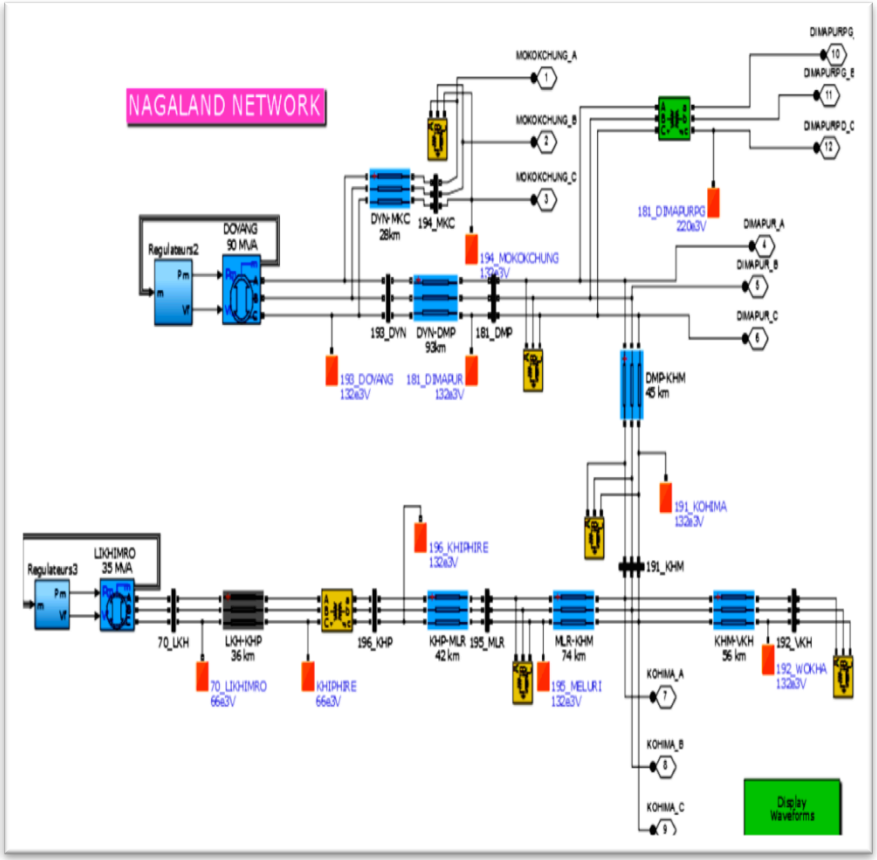


NAGALAND NETWORK

POWER MAP OF NAGALAND



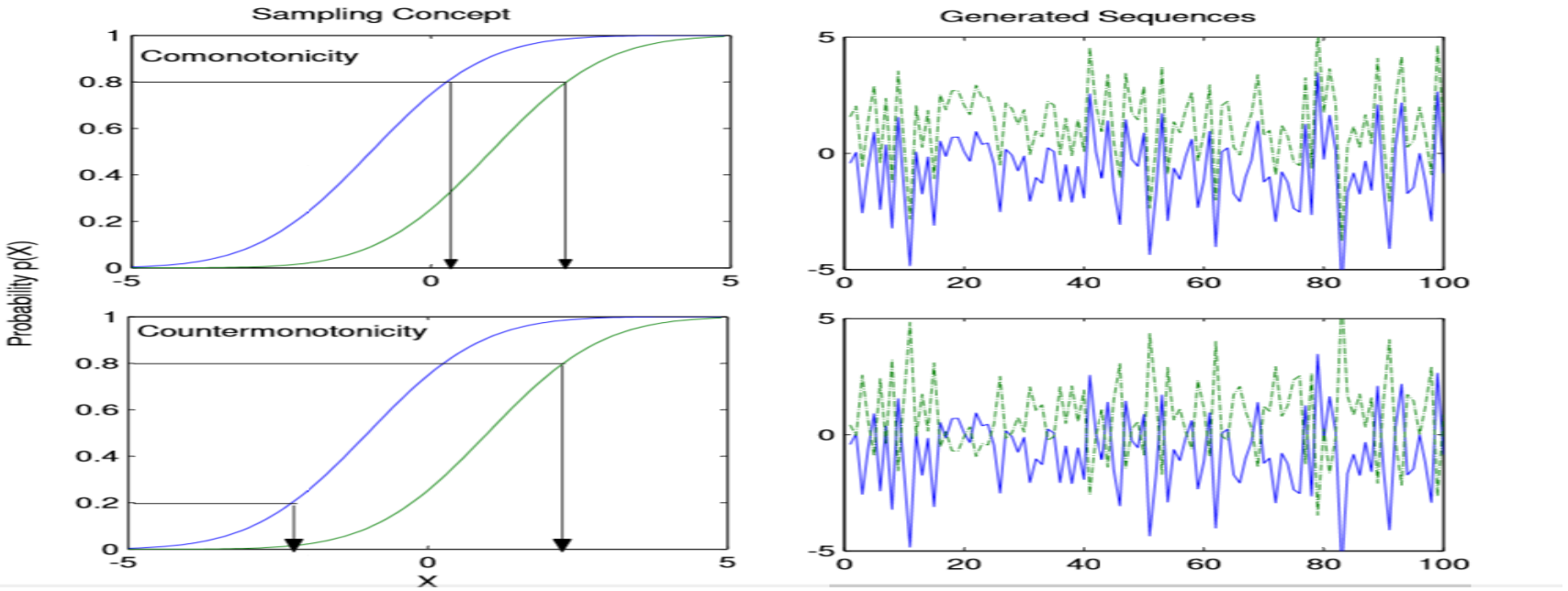
SIMULINK MODEL OF NAGALAND



Modeling of Stochastic Source in NER Grid

- Baramura (Tripura), Rokhia (Tripura), NTPS (Assam), LTPS (Assam), UmiamI (Meghalaya) and UmiamII(Meghalaya) generation plants are modeled as stochastic generation source
- 10% addition of stochastic generation is applied
- Three dependence concepts: independence comonotonic and Countermonotonic [9,12] are applied for system analysis
- Copula theory [9] is used to implement these dependence concepts

Dependence Structure



Comonotonic/Countermonotonic Sampling and Generated Sequences

- Comonotonic : $Y_i = F_{Y_i}^{-1}(U)$
- Countermonotonic : $Y_1 = F_{Y_1}^{-1}(U), Y_2 = F_{Y_1}^{-1}(1 - U)$
  where Us are independent uniform random variables.
- The produced Comonotonic sequences follow the same variations, while the Countermonotonic ones vary in an opposite fashion

Stochastic dependence structures for NER Grid

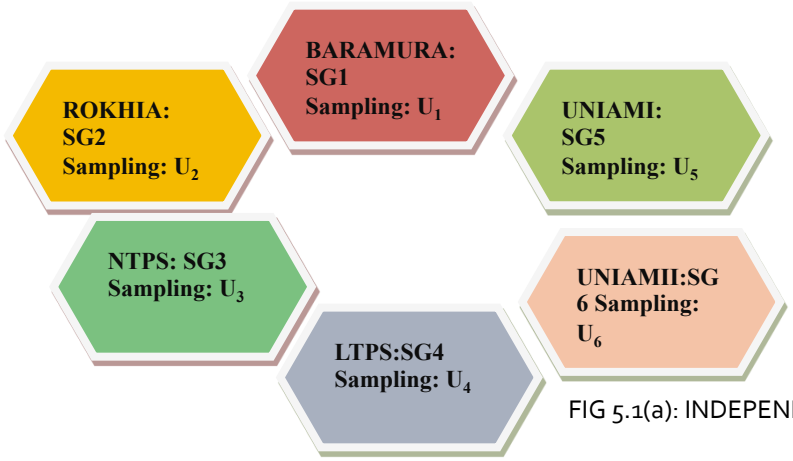


FIG 5.1(a): INDEPENDENT

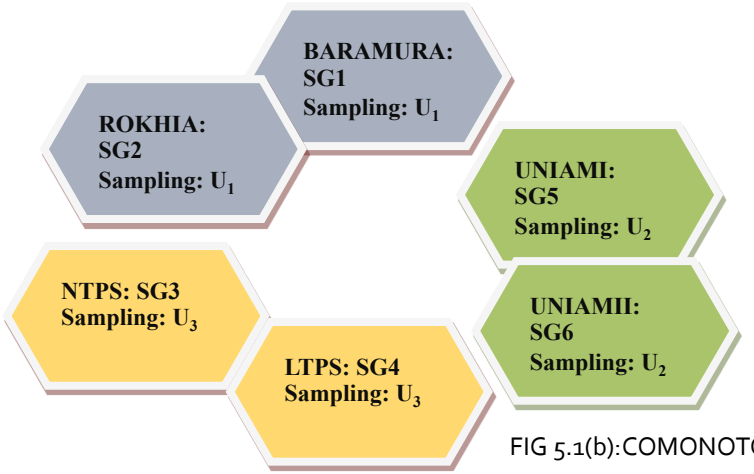


FIG 5.1(b):COMONOTONIC

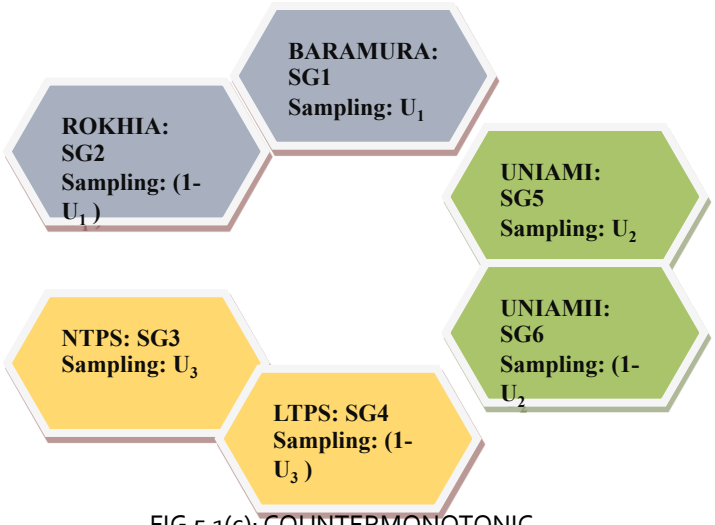


FIG 5.1(c): COUNTERMONOTONIC

Ref. 2

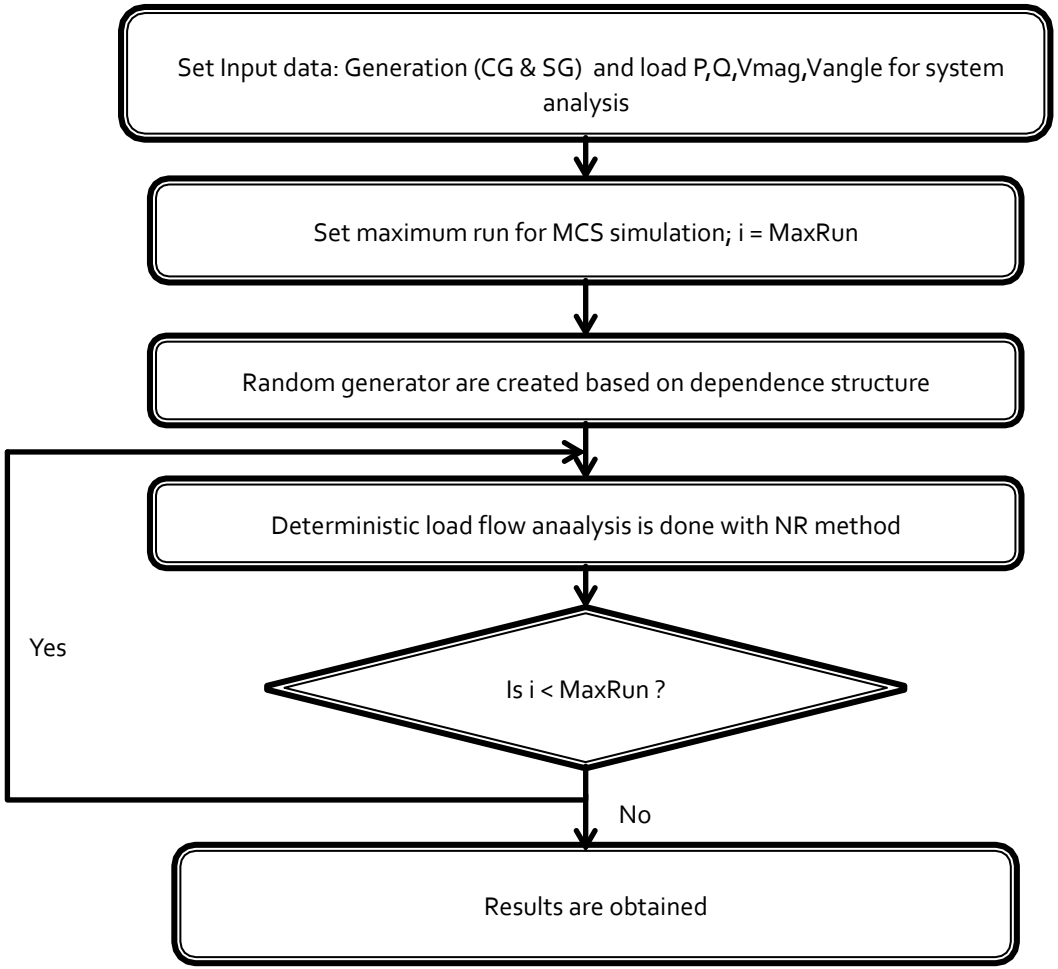
Stochastic Loadflow analysis

- Stochastic load flow analysis is performed
- A 500-sample MCS has been used for the system simulation

[Ref. 16,17,18]

Flowchart For MCS Simulation

- Generation (CG & SG) and load data are set for analysis.
- Number for run is set for MCS
- Generate uniform random number between 0 and 1 using random generator
- Perform load flow analysis based on these data for different system configuration
- Find the MCS simulation results
- Obtain statistical properties (pdf, mean, variance) of the results

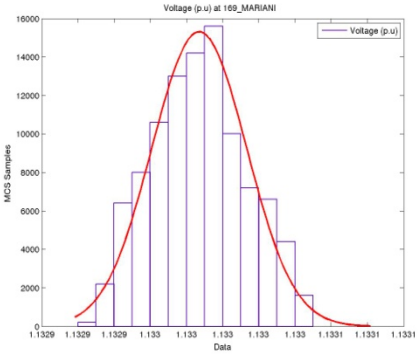


Flowchart for Monte-Carlo based stochastic load flow analysis

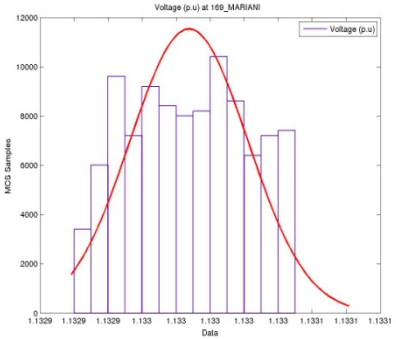
Mean and Standard deviation of Voltage Vmag at Different Nodes

NODE NAME.	INDEPENDENT MEAN	INDEPENDENT S.D	COMONOTONIC MEAN	COMONOTONIC S.D	COUNTER-MONOTONIC MEAN	COUNTER-MONOTONIC S.D
169_MARIANI	1.132987	2.60548e-5	1.132987	3.46117e-5	1.132987	1.056954e-5
124_AGARTALA	1.02895	2.70472e-5	1.02895	3.58828e-5	1.02895	1.28121e-5
123_ROKHIA	1.04319	2.20257e-5	1.04319	3.00275e-5	1.04319	8.51548e-6
121_SURJYAMANI	1.04689	2.54145e-5	1.04689	3.47069e-5	1.04689	9.78788e-6
117_TELIAMURA	1.04698	2.52937e-5	1.04698	3.44951e-5	1.04698	9.75467e-6

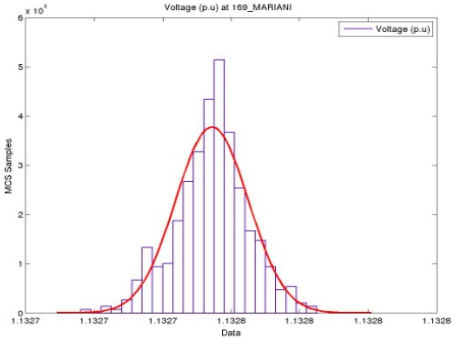
Stochastic Analysis Results: Voltage Vmag



Case-1: INDEPENDENT

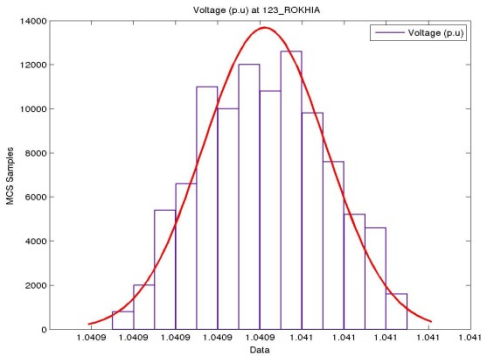


Case-2: COMONOTONIC

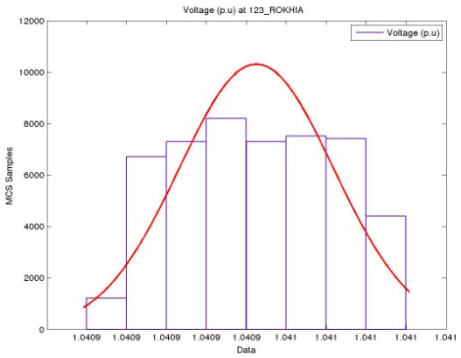


Case-3: COUNTERMONOTONIC

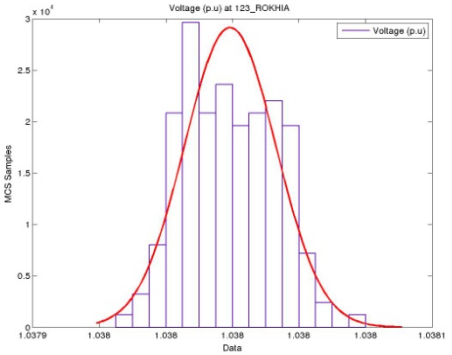
Pdf of Voltage Magnitude at 169_MARIANI



Case-1: INDEPENDENT



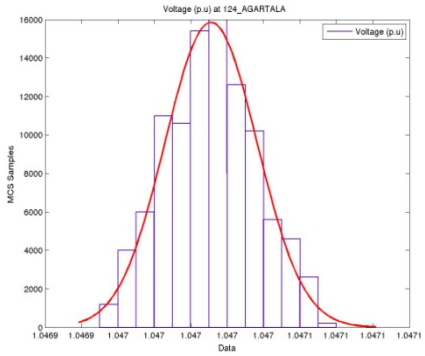
Case-2: COMONOTONIC



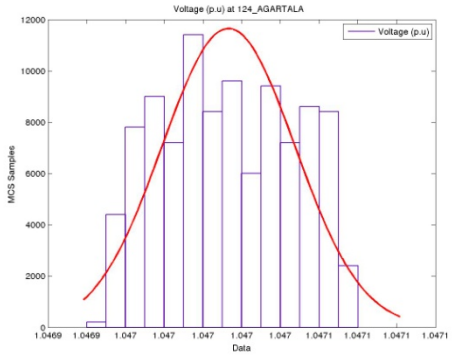
Case-3: COUNTERMONOTONIC

Pdf of Voltage Magnitude at 123_ROKHIA

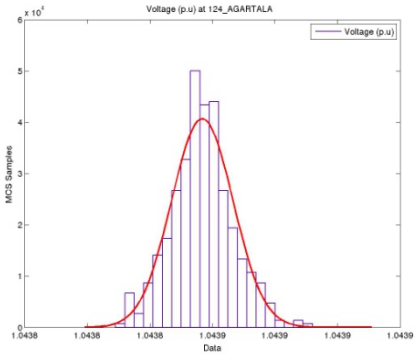
Stochastic Analysis Results: Voltage Vmag



Case-1: INDEPENDENT

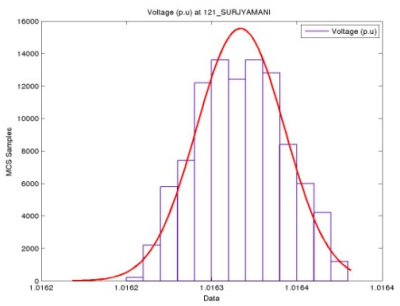


Case-2: COMONOTONIC

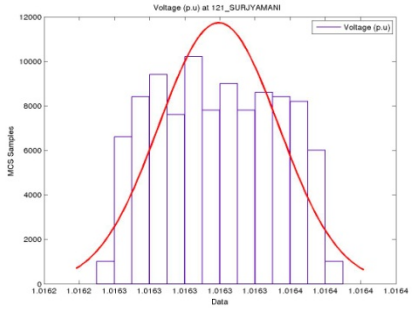


Case-3: COUNTERMONOTONIC

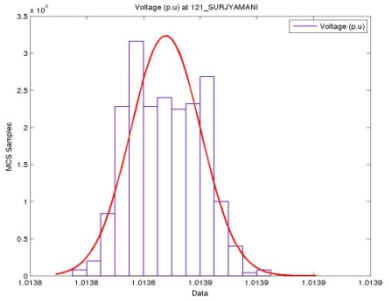
Pdf of Voltage Magnitude at 124_AGARTALA



Case-1: INDEPENDENT



Case-2: COMONOTONIC



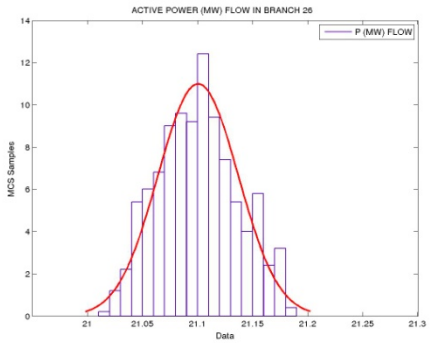
Case-3: COUNTERMONOTONIC

Pdf of Voltage Magnitude at 121_SURJYAMANI

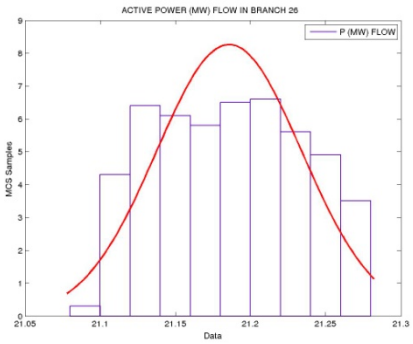
Mean and Standard deviation of Power Flow P (MW) in Different Line

FROM BUS	TO BUS	INDEPENDENT MEAN	INDEPENDENT S.D	COMONOTO-NIC MEAN	COMONOTO-NIC S.D	COUNTER-MONOTONIC MEAN	COUNTER-MONOTONIC S.D
175-TINSUKIA	177_DIBRUGARH	21.1004239689204	0.0362974788562066	21.1857492429385	0.0482895695526775	21.15646559649	0.0146726726430874
172_NAZIRA	173_SIBSAGAR	40.0043609708224	0.0163700531740159	40.0301343603456	0.0217383205409691	40.0197283578572	0.0069417283052233 8
169_MARIANI	170_JORHAT	51.0167821309235	0.0106764987365996	51.0298783933806	0.0142033612903188	51.0037676885598	0.0044868640365 7593
175-TINSUKIA	176_LEDO	20.0017586981716	0.0043487082933 0901	20.0086513892981	0.0057699646803 0605	20.0053999069878	0.0017643691208 0604
121_SURJYAMANI	120_PALATANA	-40.0101067192482	0.0121902460859790	-39.9955971693468	0.0157546739583094	-40.0076284120257	0.0070332756359 5840

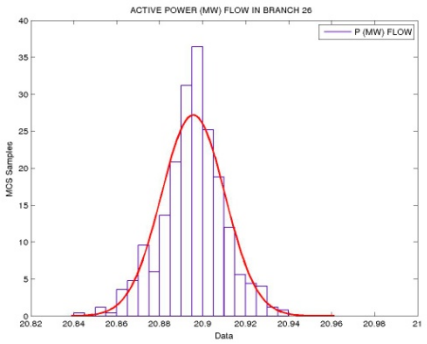
Stochastic Analysis Results :Active Power P (MW) Flow



Case-1: INDEPENDENT

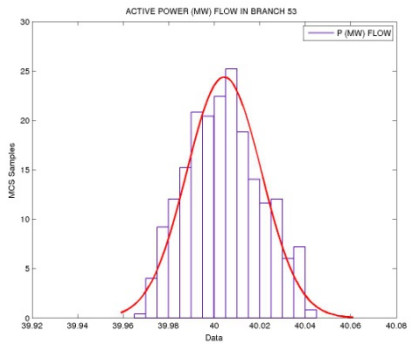


Case-2: COMONOTONIC

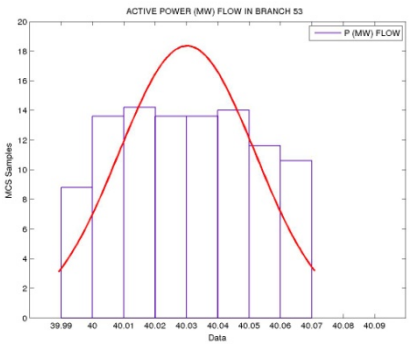


Case-3: COUNTERMONOTONIC

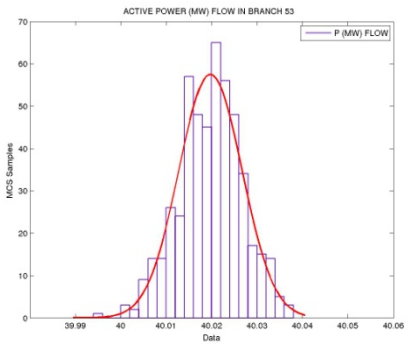
P_FLOW IN LINE 175-TINSUKIA AND 177_DIBRUGARH



Case-1: INDEPENDENT



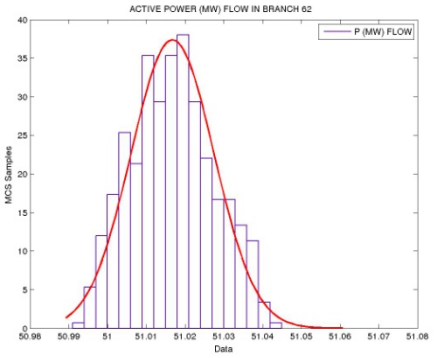
Case-2: COMONOTONIC



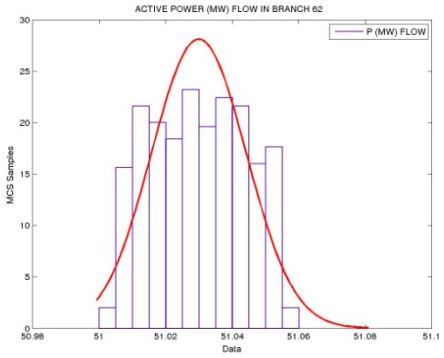
Case-3: COUNTERMONOTONIC

P_FLOW IN LINE 172_NAZIRA-173_SIBSAGAR

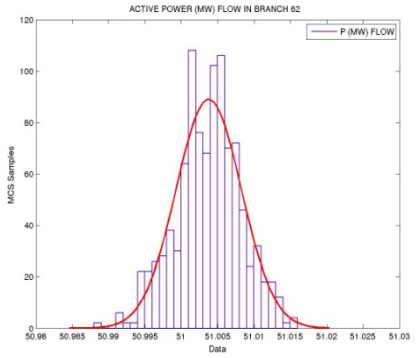
Stochastic Analysis Results :Active Power P (MW) Flow



Case-1: INDEPENDENT

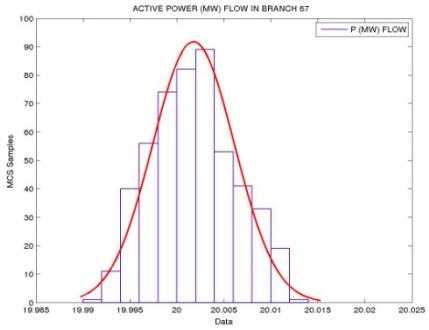


Case-2: COMONOTONIC

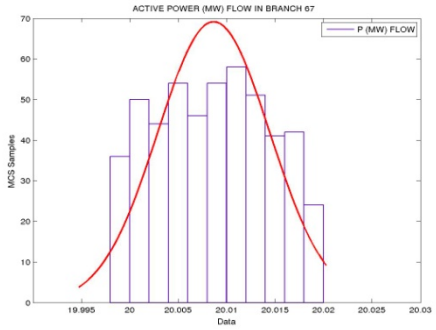


Case-3: COUNTERMONONOTONIC

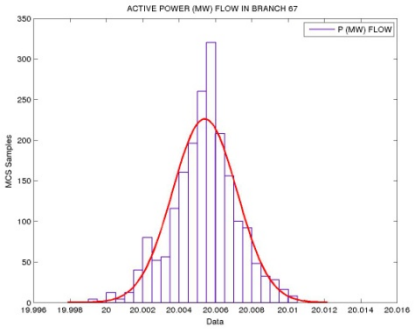
P_FLOW IN LINE 169_MARIANI AND 170_JORHAT



Case-1: INDEPENDENT



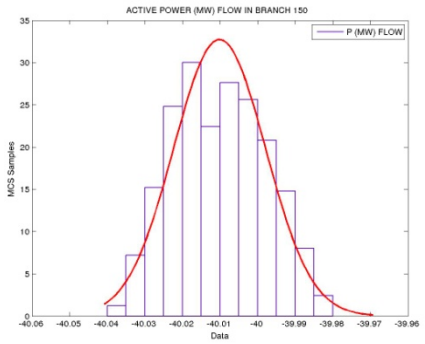
Case-2: COMONOTONIC



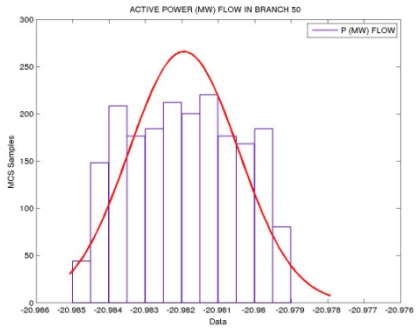
Case-3: COUNTERMONOTONIC

P_FLOW IN LINE 175-TINSUKIA AND 176_LEDO

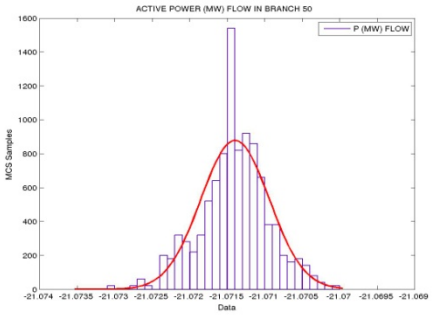
Stochastic Analysis Results :Active Power P (MW) Flow



Case-1: INDEPENDENT

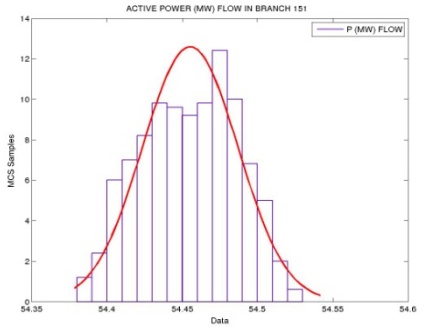


Case-2: COMONOTONIC

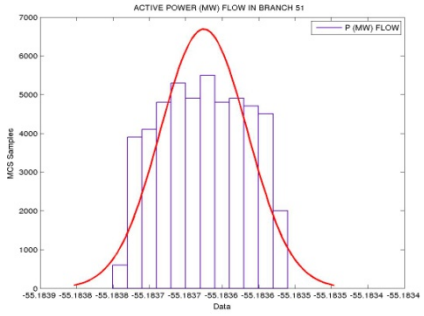


Case-3: COUNTERMONOTONIC

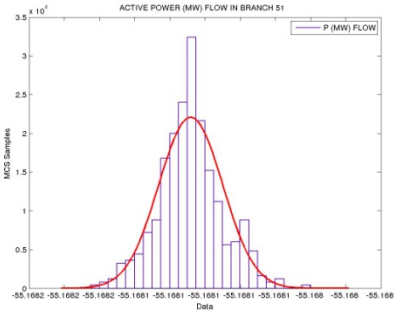
P_FLOW IN LINE 121_SURJYAMANI AND 120_PALATANA



Case-1: INDEPENDENT



Case-2: COMONOTONIC



Case-3: COUNTERMONOTONIC

P_FLOW IN LINE 123_ROKHIA AND 122_UDAIPUR

Result Discussion

- The mean values of line power flows and voltage magnitudes at different nodes are the same for the three dependence cases, while the standard deviations are different
- For the independent case S.D is less than that of for the case of comonotonic
- The independent case can be recognized as the 'best-case scenario', as it gives distributions with minimal dispersion for all the system lines and nodes, the comonotonic (for SG units) vary between the system lines and nodes: for the lines Surjamaninagar-Palatana, Rokhia-Udaipur, Tinsukia-Ledo (lines connected to the system CG) the dispersion of the distributions is less in case of independent scenario while maximum in case of comonotonic.
- the presence of stochastic generation in the system results to highly bidirectional power flows.

Conclusion

- The result shows the importance of the investigation of all different dependence structures for system design purpose, since different dependence structure can provide different distributions for different lines in the system.
- The system should be able to support both power flow directions, so the system design should be performed based on the higher obtained values
- Design based on the Stochastic Bounds Methodology is a design that is based on the worst case of aggregated stochastic stress for the system
- The advantage of the use of the methodology is that the system designer may measure the risk of exceeding the system safety margins for these worst-case scenarios and take respective actions to reduce it
- The maximum stress on line may be confronted by the installation of a FACTS device in the line, in order to redirect the power
- The uncertainty analysis of NER Grid (India) and individual states of North East with stochastic generation is done first time

Future work

- Modeling of NER Grid with integration of SG units for different dependence structures at distribution network and perform uncertainty analysis
- Analysis of other Indian Grid applying same methodology
- Application of other techniques to analysis the same model.
- Draft preparation of a conference paper

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Thanks

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