Monitoring Analysis and Control of Power Grids using WAMS

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Supervised by:-

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Overview

Situational Awareness	• Overview • Complexity
Available Transfer Capability	• Brief Introduction • Problem Formulation
Pseudo PMU Emulation (PPMU)	• PPMU for quasi-static simulation • Data Generation
Real Time ATC Estimation	• ANN based ATC estimator • Implementation on RTDS

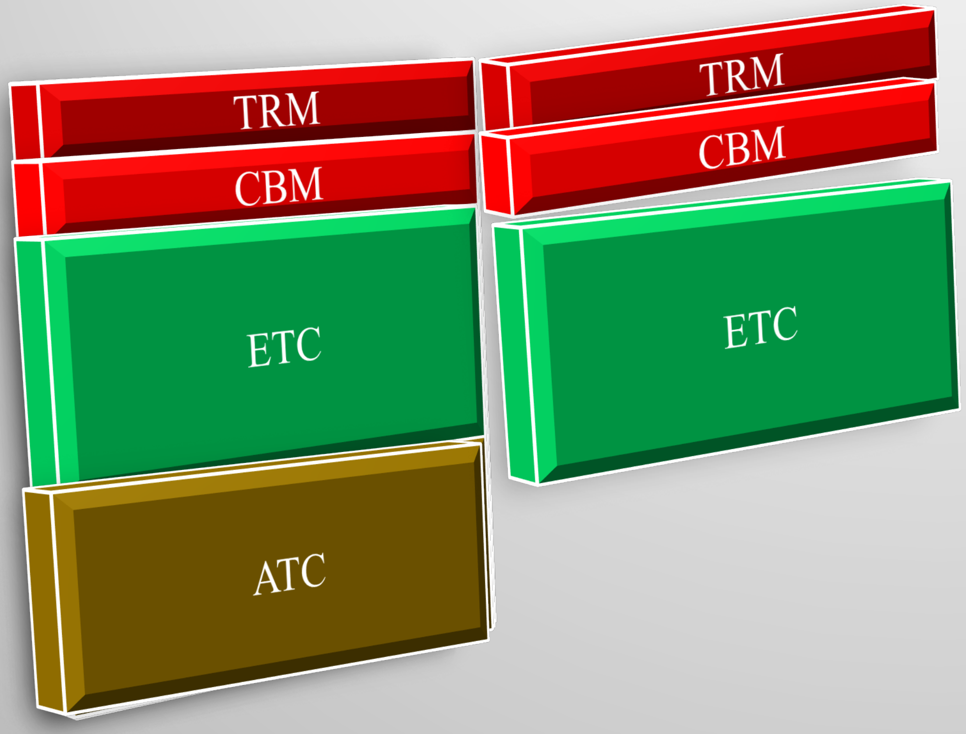
Situational Awareness

- Power system monitoring is being regularly done to grasp the operational situation of the power system.
- Availability of adequate information pertaining the to health of the system would ensure appropriate decision making by the power system operators.
- The complexity of the system monitoring has increased many folds with major contributors being the emphasis on large scale integration of renewable sources at both the transmission and distribution levels.
- Integration of renewables increases the uncertainties of the system operation at same time reduce the grid inertia.

Situational Awareness: Continued

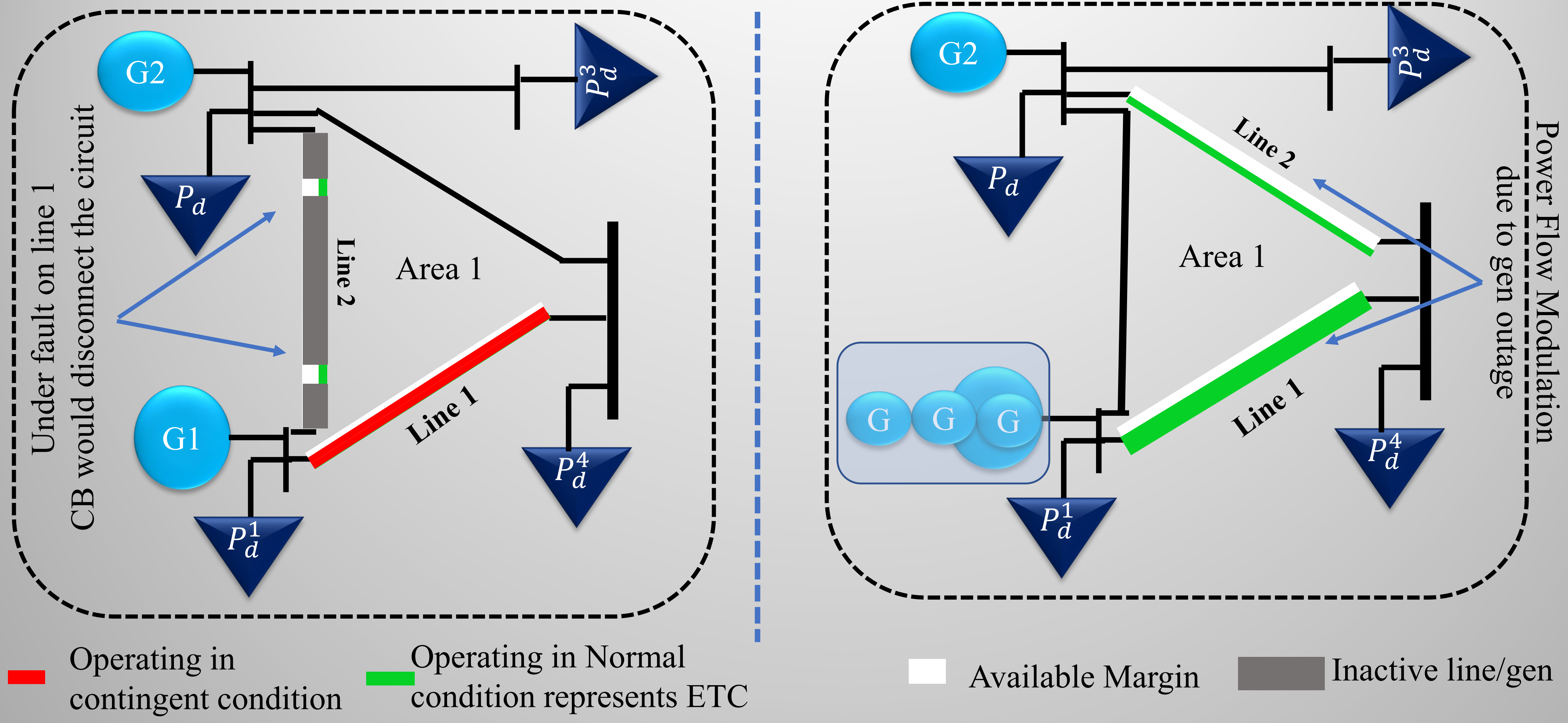
- With large scale integration of DG at distribution levels and appraisal of prosumer technology, the conventional distribution networks converted to active distribution networks.
- The active distribution networks with advanced monitoring and control capability if allowed could possibly inject power back to the grid at transmission levels.
- On account of such interaction traditional methods of system analysis and monitoring developed with consideration of disjoint transmission and distribution would have to be revisited and recalibrated for adequacy.
- The increased renewable penetration also effects the power flows through the line and hence the assessment of transmission capability remaining in the system becomes an important factor.

AVAILABLE TRANSFER CAPABILTY

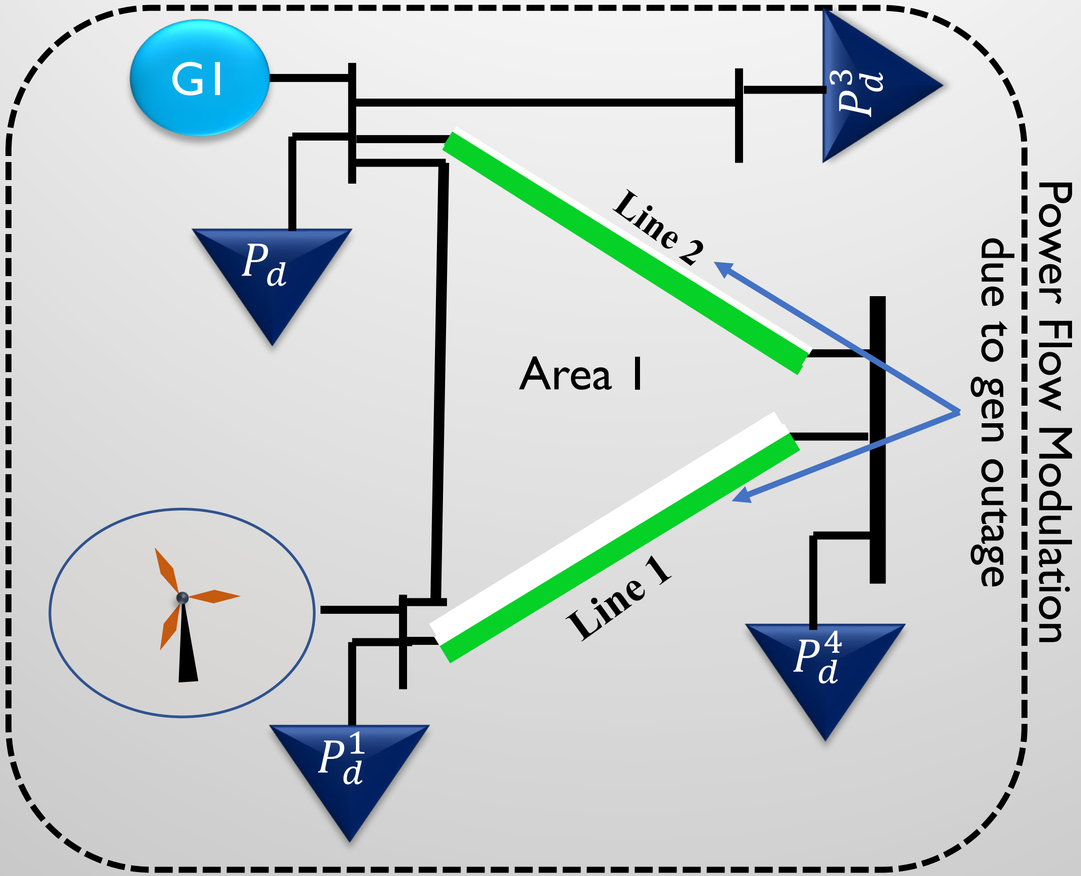


AVAILABLE TRANSFER CAPABILTY

ATC: Illustrative Example



ATC: Illustrative Example



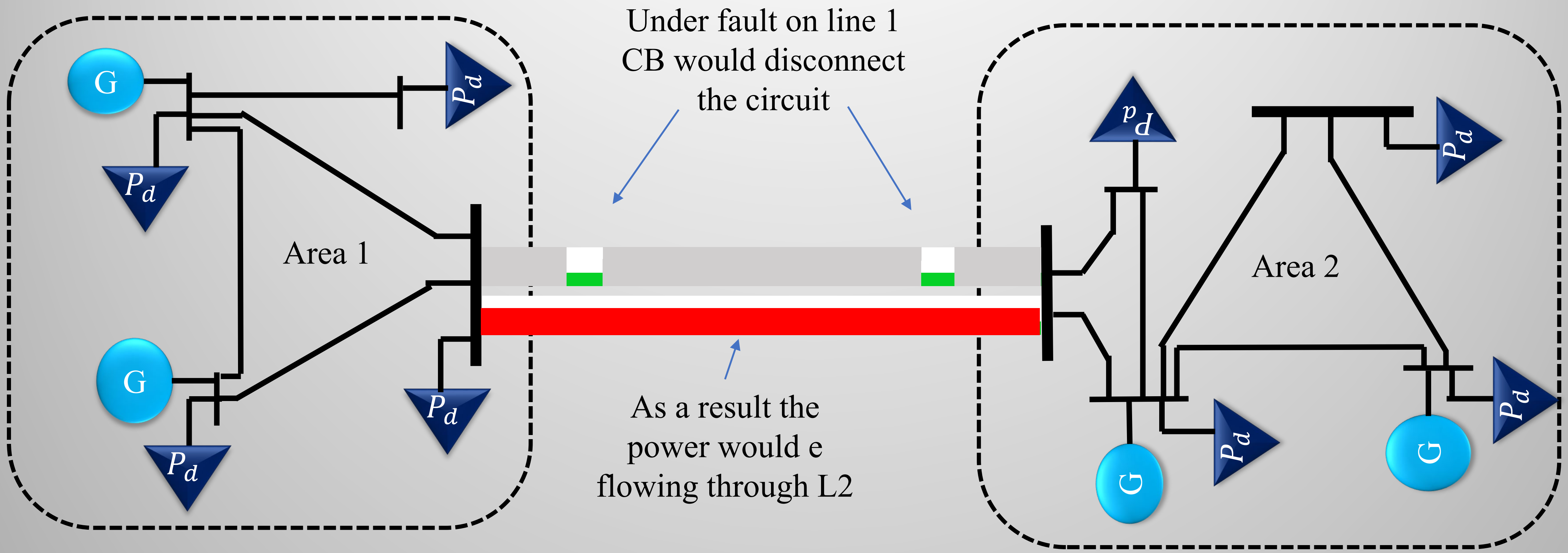
Operating in contingent condition

Operating in Normal condition represents ETC

Available Margin

Inactive line/gen

ATC: Illustrative Example



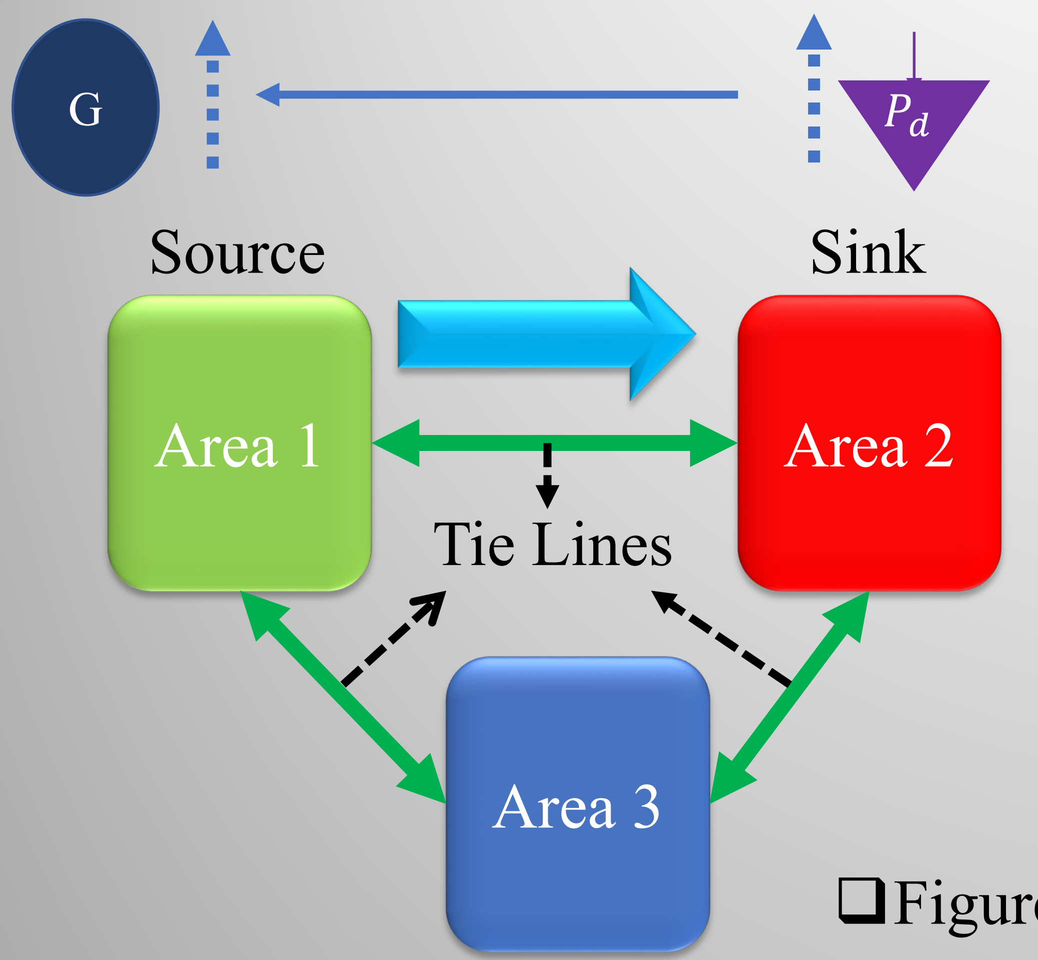
Operating in contingent condition

Operating in Normal condition represents ETC

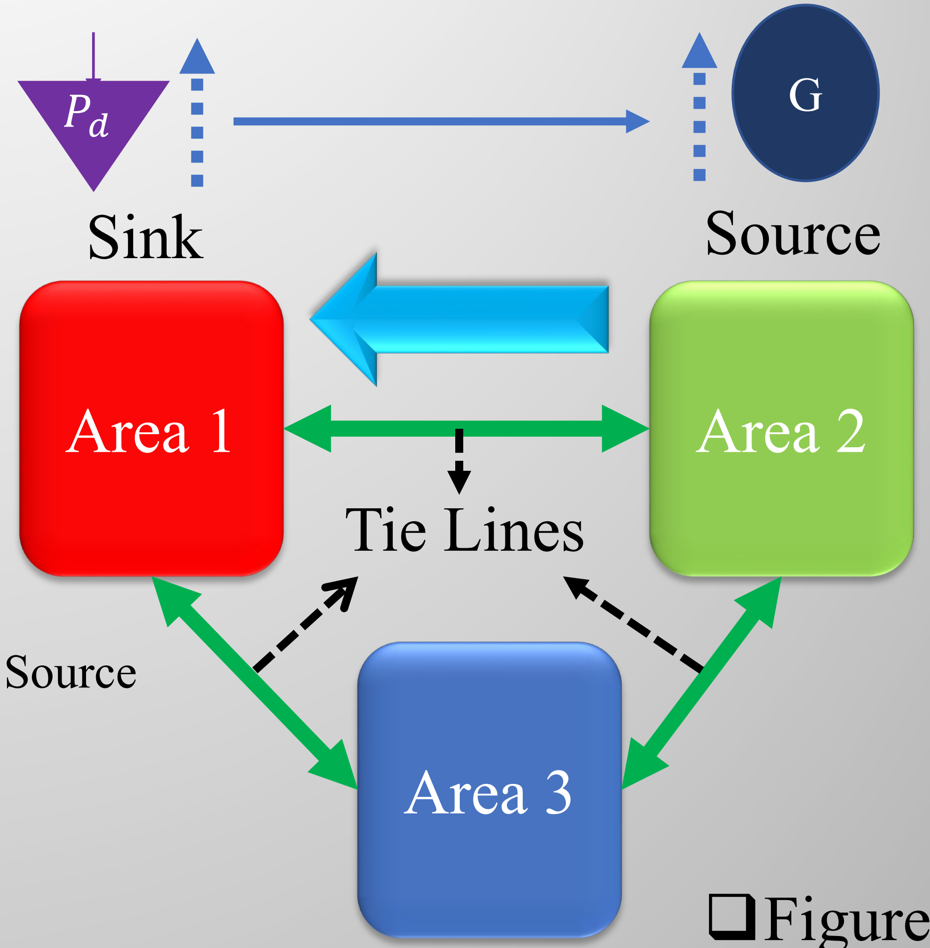
Available Margin

Inactive line

Schematic Representation of ATC evaluation

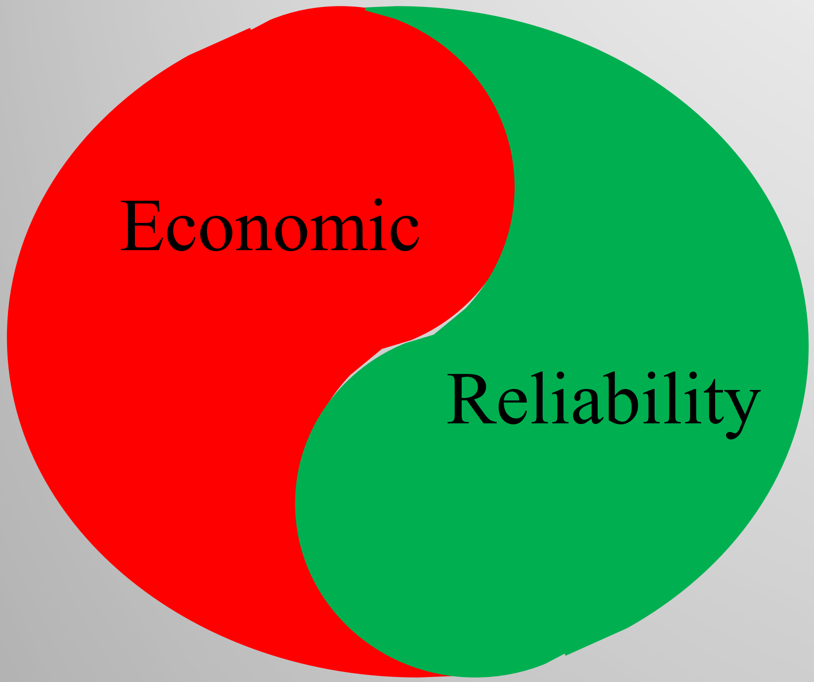


❑Figure. 1

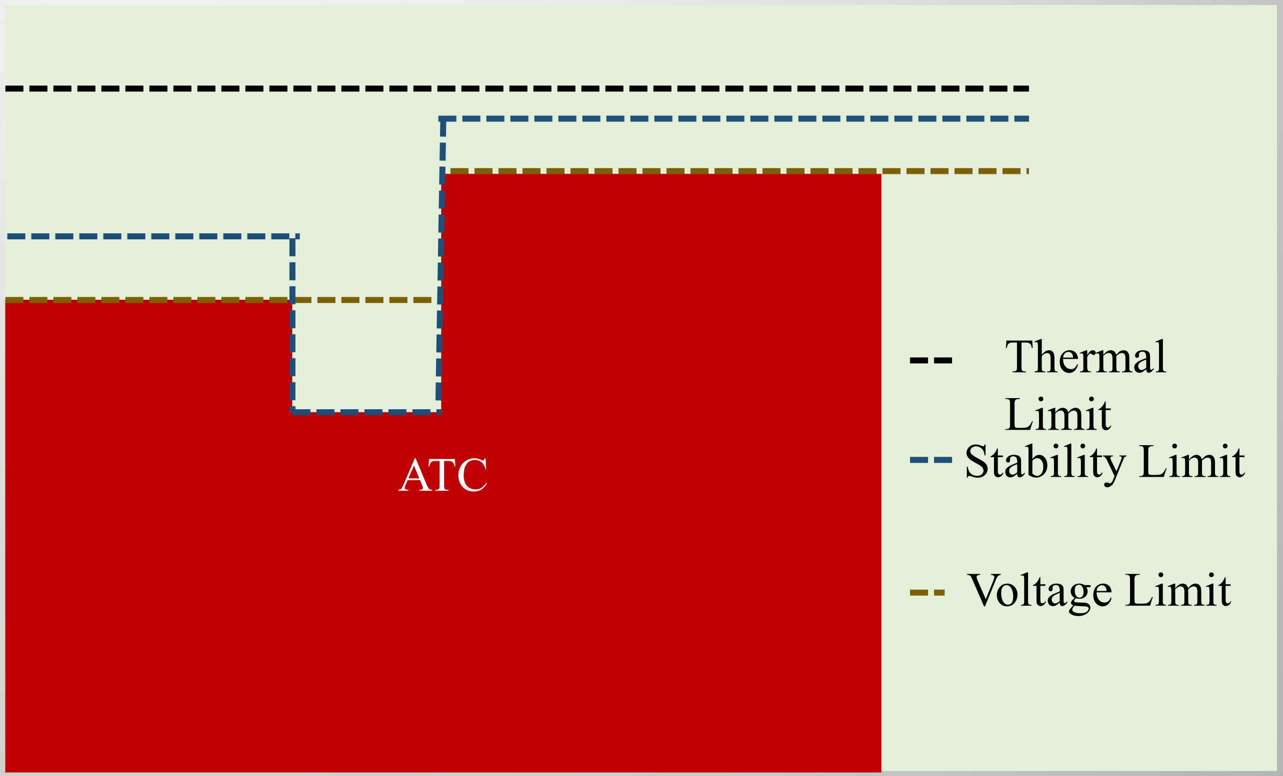


❑Figure. II

Available Transmission Capability



❑Figure. 3



❑Figure. 4

- Problem Formulation

The value of ATC in (1) can be obtained by maximizing the demand in the sink area of the system, expressed mathematically as

$$Max\ (f(x)) \quad \ldots(2)$$

Where,

$$f(x) = \sum_{i=1}^{n_{sink}} x_i - \sum_{i=1}^{n_{sink}} x_{i0} \quad \ldots(3)$$

Here,

n_{sink} is the number of buses in sink area

x_i is the load at i^{th} bus.

x_{io} is the initial load at the i^{th} bus

Constraints

- Equality Constraints

The power quality constraints.

$$\sum_{i=1}^{M} P_{gi} - \sum_{i=1}^{N} P_{di} - \sum_{i=1}^{N}\sum_{J=1}^{N} V_i V_j Y_{ij} \cos\left(\theta_{ij} - \delta_i + \delta_j\right) = 0 \qquad \ldots(3)$$

$$\sum_{i=1}^{M} Q_{gi} - \sum_{i=1}^{N} Q_{di} - \sum_{i=1}^{N}\sum_{J=1}^{N} V_i V_j Y_{ij} \sin\left(\theta_{ij} - \delta_i + \delta_j\right) = 0 \qquad \ldots(4)$$

Here, $i, j \in 1,2, \cdots N$

- Inequality Constraints

$$P_{gi}^{min} \leq \mathrm{P_{gi}} \leq P_{gi}^{max} \qquad i \in 1,2 \cdots M \qquad \ldots(4)$$

$$Q_{gi}^{min} \leq \mathrm{Q_{gi}} \leq Q_{gi}^{max} \qquad i \in 1,2 \cdots M \qquad \ldots(5)$$

$$V_{i}^{min} \leq \mathrm{V_{i}} \leq V_{i}^{max} \qquad i \in 1,2 \cdots N \qquad \ldots(6)$$

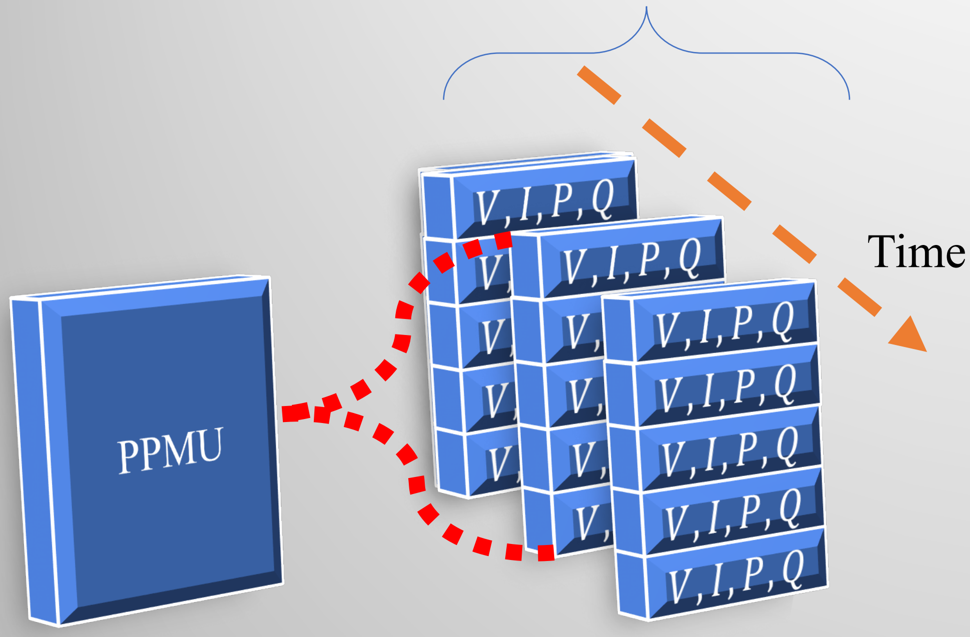
$$P_{i,j}^{min} \leq P_{\mathrm{i,j}} \leq P_{i,j}^{max} \qquad i \in 1,2 \cdots N \quad j \in 1,2 \cdots N \;\&\; j \neq i \qquad \ldots(7)$$

$$x_{min} \leq x \leq x^{max} \qquad \ldots(8)$$

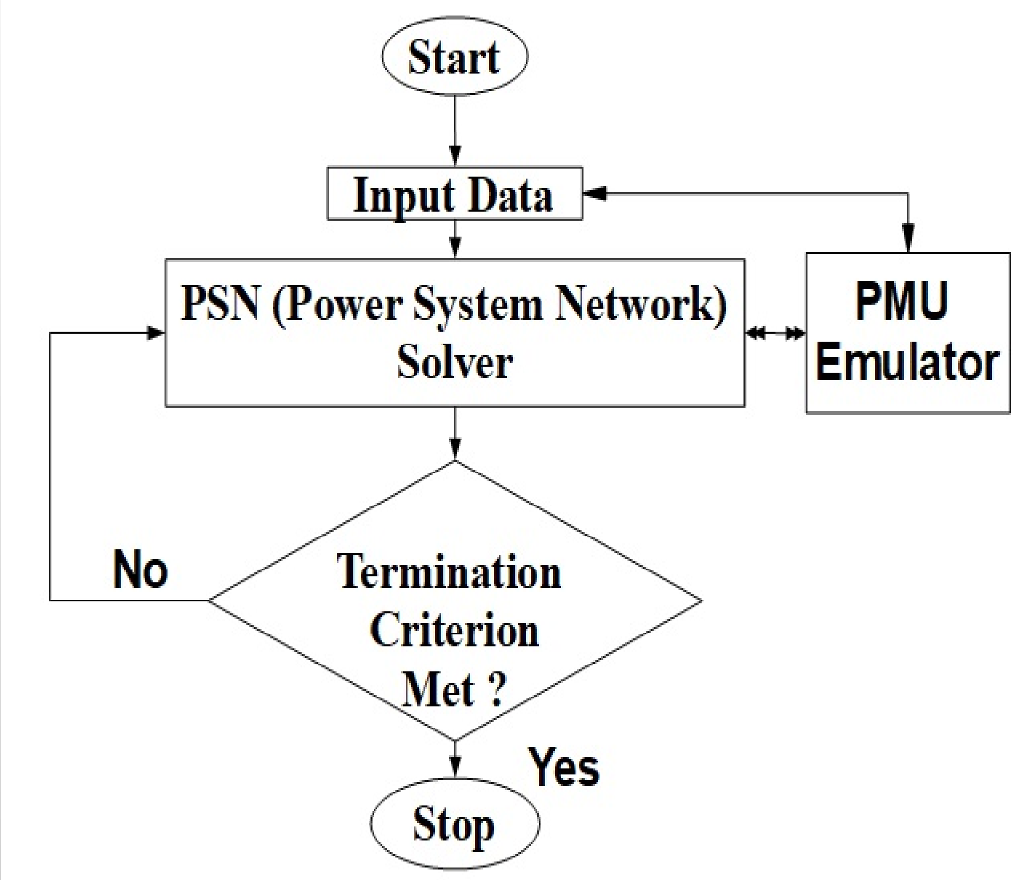
Here,
M→ number of generation buses.
N→ number of load buses

Pseudo-PMU Emulation for Quasi-Static Analysis

Power System Scenarios

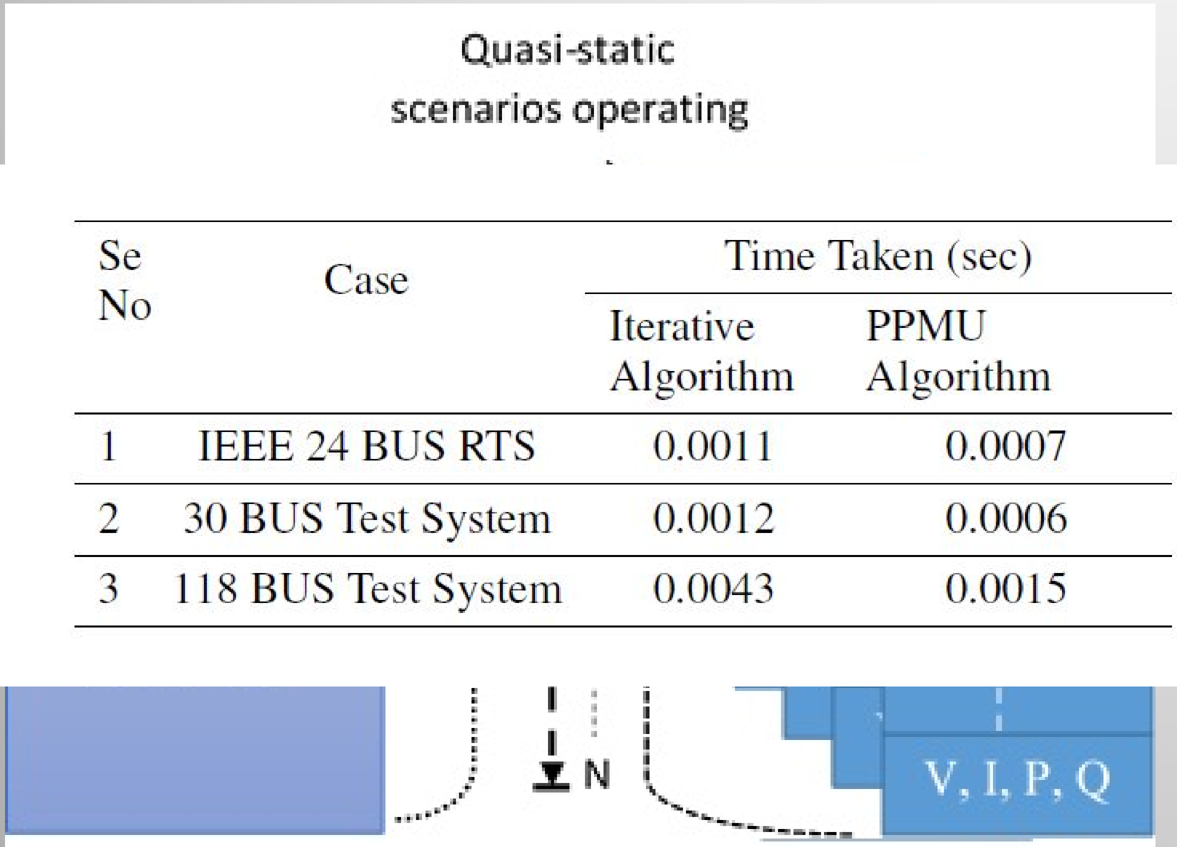


- Figure. 5



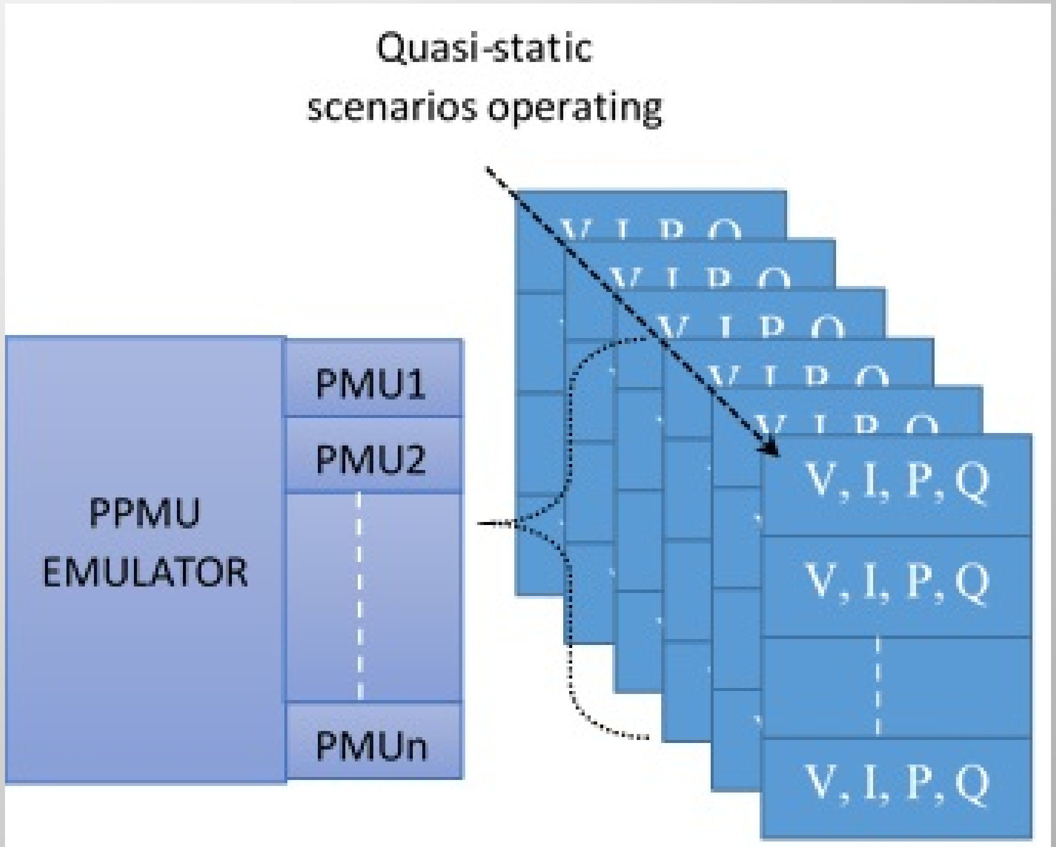
- Figure. 6

PMU EMULATION:- Comparison of Conventional and PMU Emulator



Se No	Case	Time Taken (sec)	
		Iterative Algorithm	PPMU Algorithm
1	IEEE 24 BUS RTS	0.0011	0.0007
2	30 BUS Test System	0.0012	0.0006
3	118 BUS Test System	0.0043	0.0015

- Figure. 7

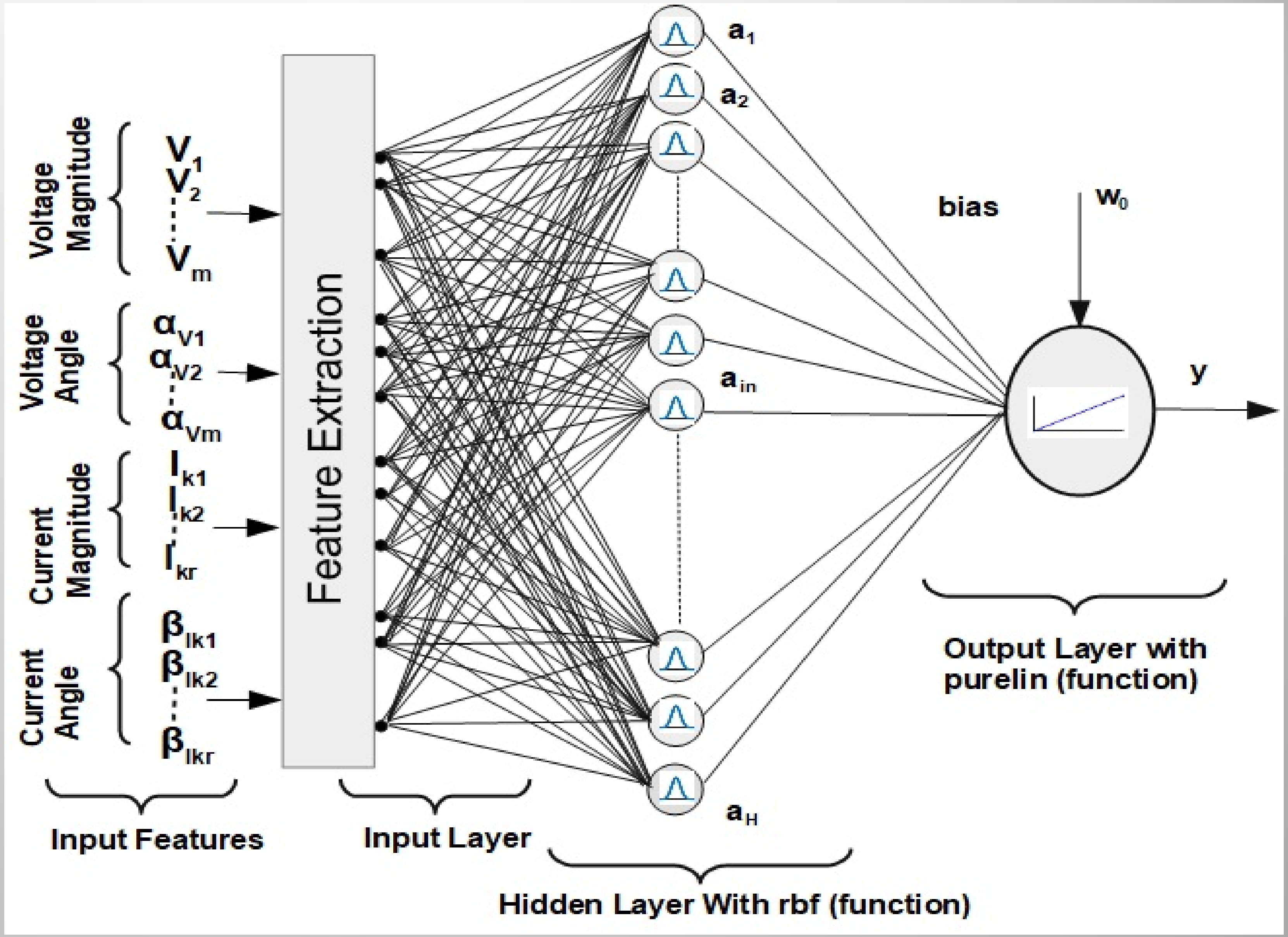


- Figure. 8

Real Time ATC Estimation using ANN

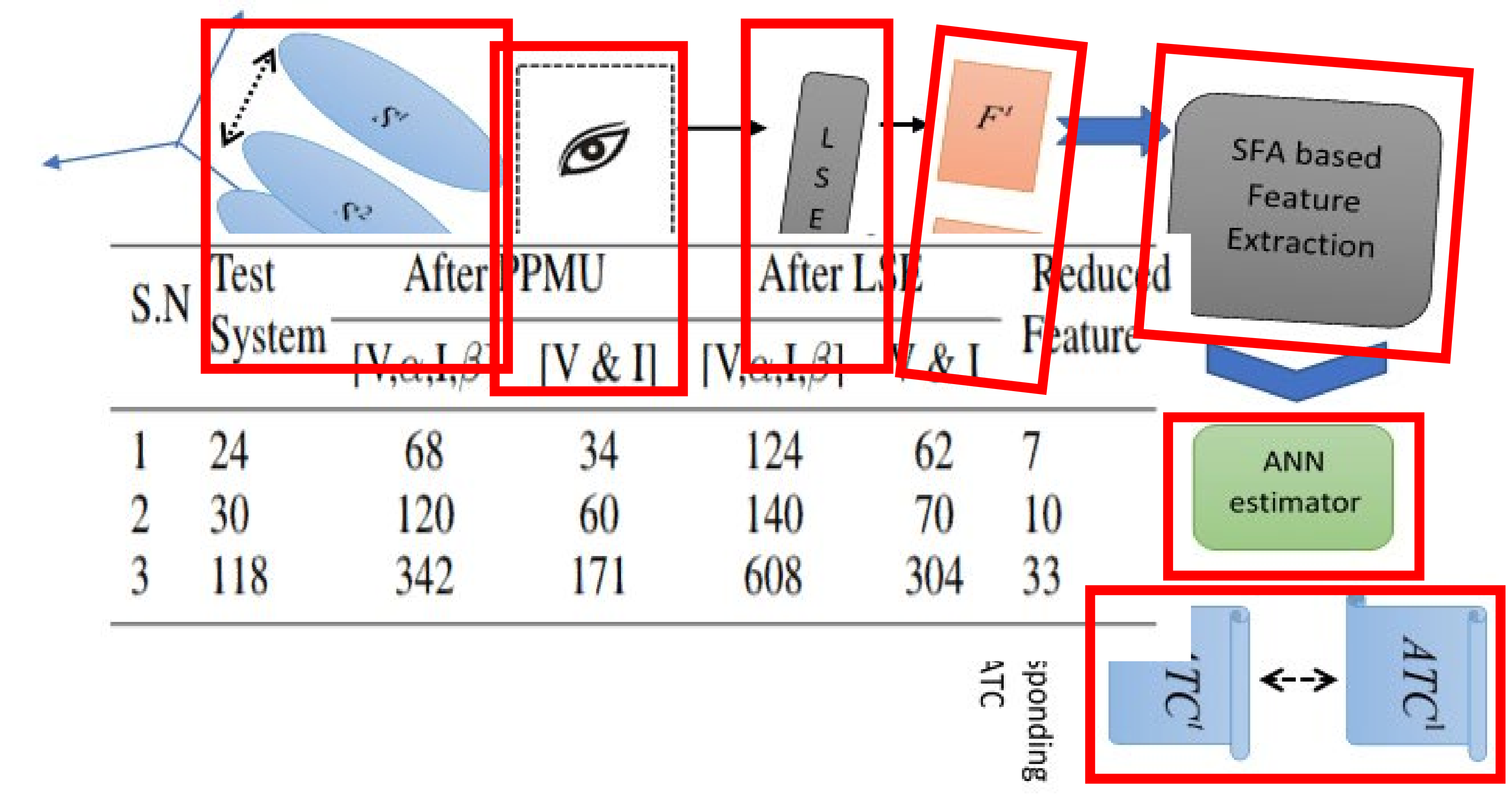
The architecture of ANN presented used has been given in Figure. 9

- Figure 9



Feature Extraction: - Schematic Representation

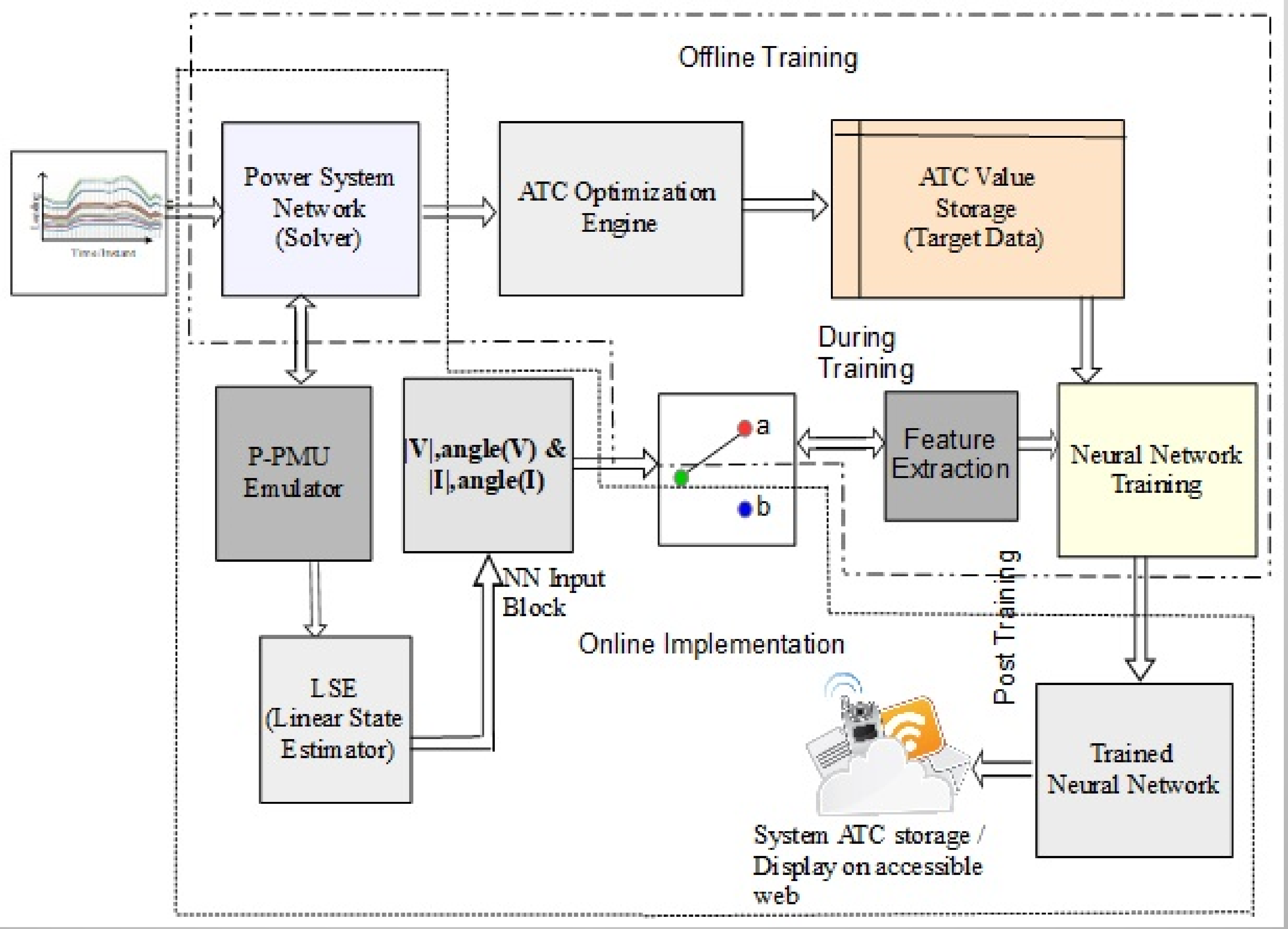
- Figure 10



S.N	Test System	After PPMU [V,α,I,β]	After PPMU [V & I]	After LSE [V,α,I,β]	After LSE [V & I]	Reduced Feature
1	24	68	34	124	62	7
2	30	120	60	140	70	10
3	118	342	171	608	304	33

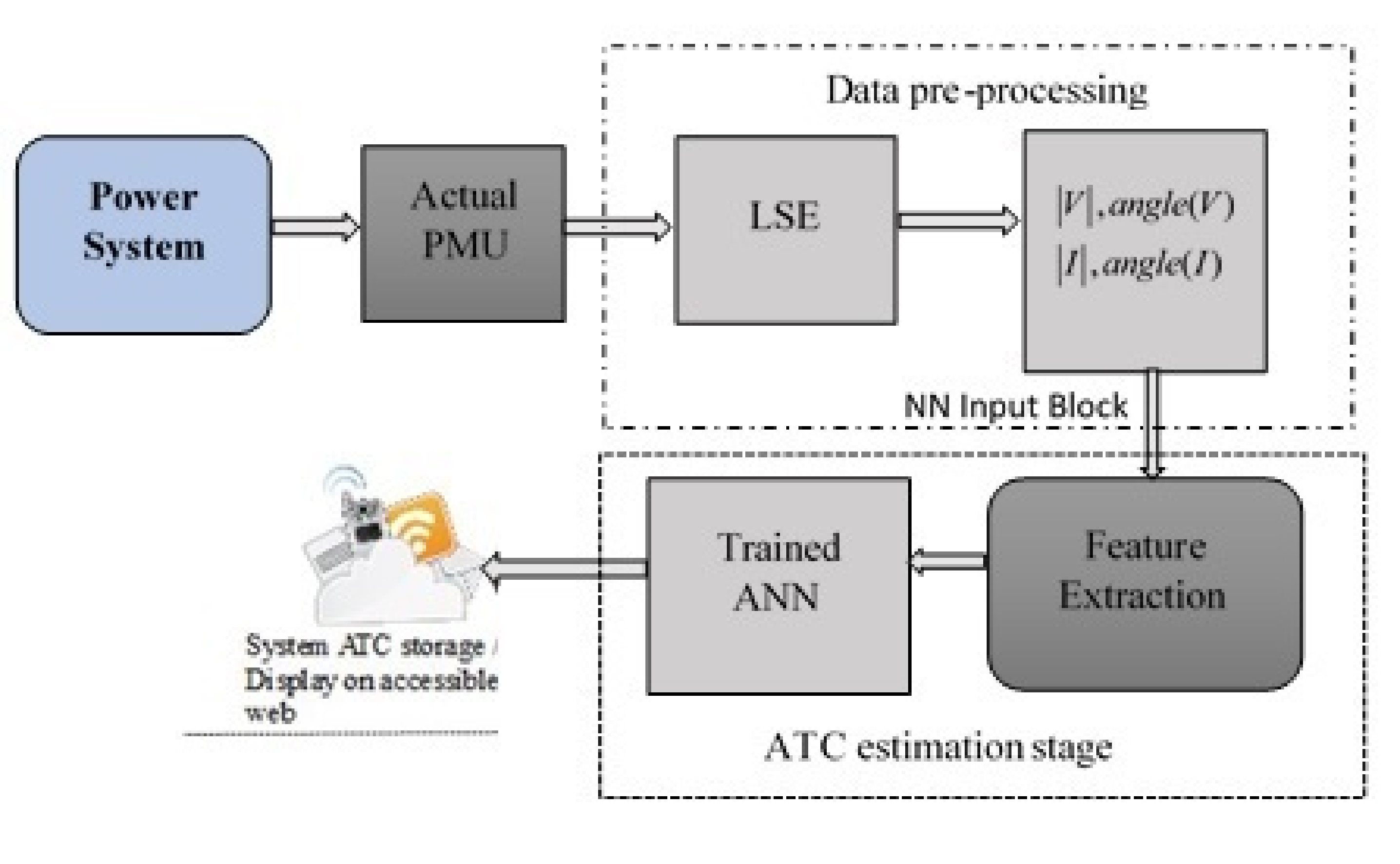
Schematic: -Software Based Development of the Proposed Method

- Figure 10(a)



Practical Implementation of the proposed Method

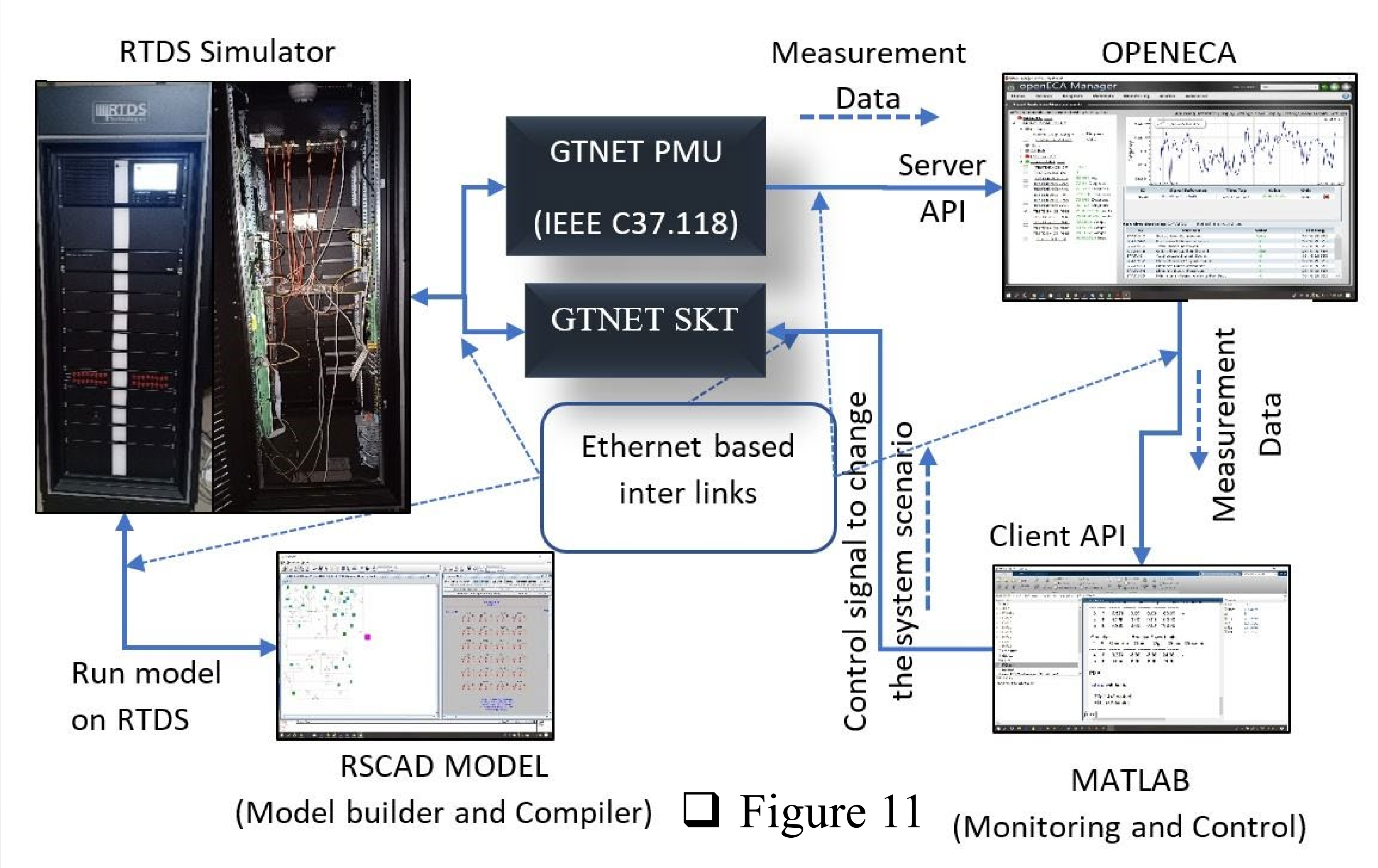
- The PSN solver and the input scenario have been replaced by actual power grid where as PPMU emulator has been replaced by actual PMU.
- The PMU measurements have been directly sent to the data pre-processing stage (i.e. LSE and Feature Extraction) for ATC estimation by the trained ANN.



❑ Figure 10(b)

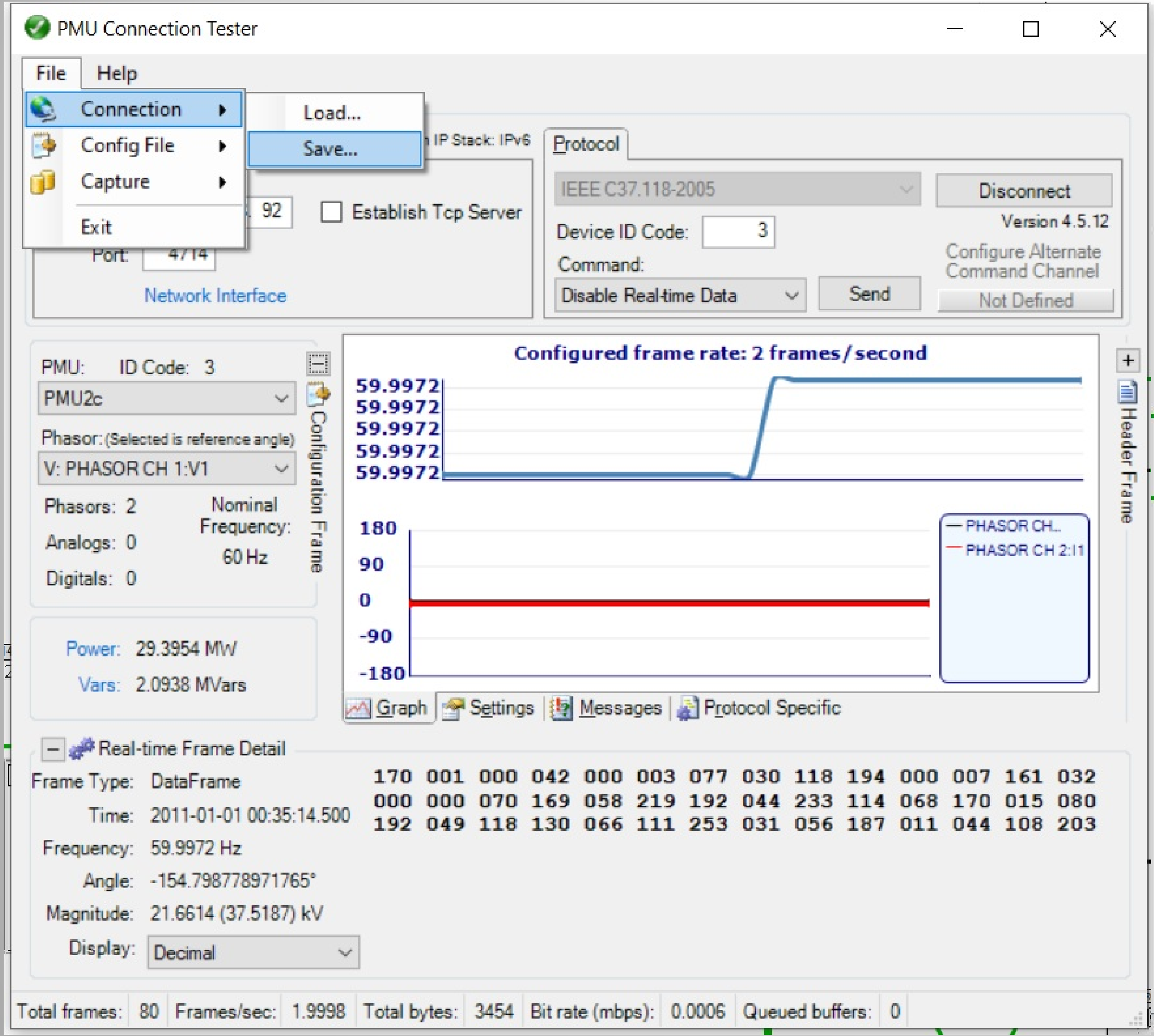
Authentication in real time Using Real-Time Digital Simulator

- This communication is established through ‘GTNET SKT’ protocol. The ‘GTNET SKT’ protocol is capable of handling data streams with an update frequency of 2 kHz (maximum).
- A schematic representation of the process has been shown in Figure.9.

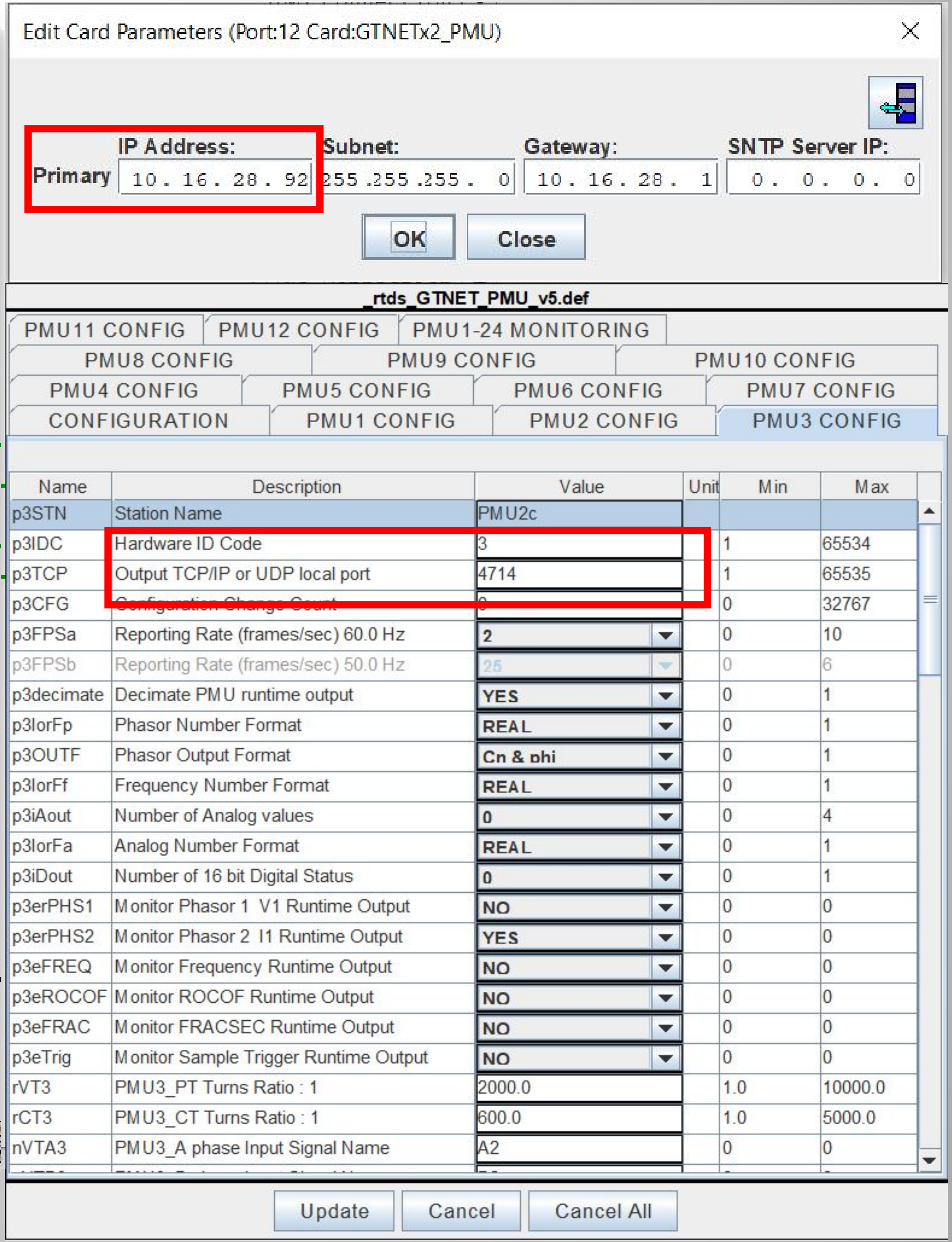


❑ Figure 11

Configuring GTNET PMU and Open PMU Connection Tester and OpenECA to MATLAB Interface



PMU Connection Tester
File
Help
Connection
Config File
Capture
Exit
Load...
Save...
IP Stack: IPv6
Establish Tcp Server
Port: 4714
Network Interface
Protocol
IEEE C37.118-2005
Disconnect
Version 4.5.12
Device ID Code: 3
Command:
Disable Real-time Data
Send
Configure Alternate Command Channel
Not Defined
PMU: ID Code: 3
PMU2c
Phasor: (Selected is reference angle)
V: PHASOR CH 1:V1
Phasors: 2
Analogs: 0
Digitals: 0
Nominal Frequency: 60 Hz
Configuration Frame
Header Frame
Configured frame rate: 2 frames/second
59.9972
180
90
0
-90
-180
PHASOR CH...
PHASOR CH 2:I1
Power: 29.3954 MW
Vars: 2.0938 MVars
Graph
Settings
Messages
Protocol Specific
Real-time Frame Detail
Frame Type: DataFrame
Time: 2011-01-01 00:35:14.500
Frequency: 59.9972 Hz
Angle: -154.798778971765°
Magnitude: 21.6614 (37.5187) kV
Display: Decimal
170 001 000 042 000 003 077 030 118 194 000 007 161 032
000 000 070 169 058 219 192 044 233 114 068 170 015 080
192 049 118 130 066 111 253 031 056 187 011 044 108 203
Total frames: 80
Frames/sec: 1.9998
Total bytes: 3454
Bit rate (mbps): 0.0006
Queued buffers: 0



Edit Card Parameters (Port:12 Card:GTNETx2_PMU)
Primary
IP Address: 10 . 16 . 28 . 92
Subnet: 255 .255 .255 . 0
Gateway: 10 . 16 . 28 . 1
SNTP Server IP: 0 . 0 . 0 . 0
OK
Close
_rtds_GTNET_PMU_v5.def
PMU11 CONFIG
PMU12 CONFIG
PMU1-24 MONITORING
PMU8 CONFIG
PMU9 CONFIG
PMU10 CONFIG
PMU4 CONFIG
PMU5 CONFIG
PMU6 CONFIG
PMU7 CONFIG
CONFIGURATION
PMU1 CONFIG
PMU2 CONFIG
PMU3 CONFIG
Name | Description | Value | Unit | Min | Max
p3STN | Station Name | PMU2c
p3IDC | Hardware ID Code | 3 | 1 | 65534
p3TCP | Output TCP/IP or UDP local port | 4714 | 1 | 65535
p3CFG | Configuration Change Count | 0 | 0 | 32767
p3FPSa | Reporting Rate (frames/sec) 60.0 Hz | 2 | 0 | 10
p3FPSb | Reporting Rate (frames/sec) 50.0 Hz | 25 | 0 | 6
p3decimate | Decimate PMU runtime output | YES | 0 | 1
p3IorFp | Phasor Number Format | REAL | 0 | 1
p3OUTF | Phasor Output Format | Cn & phi | 0 | 1
p3IorFf | Frequency Number Format | REAL | 0 | 1
p3iAout | Number of Analog values | 0 | 0 | 4
p3IorFa | Analog Number Format | REAL | 0 | 1
p3iDout | Number of 16 bit Digital Status | 0 | 0 | 1
p3erPHS1 | Monitor Phasor 1 V1 Runtime Output | NO | 0 | 0
p3erPHS2 | Monitor Phasor 2 I1 Runtime Output | YES | 0 | 0
p3eFREQ | Monitor Frequency Runtime Output | NO | 0 | 0
p3eROCOF | Monitor ROCOF Runtime Output | NO | 0 | 0
p3eFRAC | Monitor FRACSEC Runtime Output | NO | 0 | 0
p3eTrig | Monitor Sample Trigger Runtime Output | NO | 0 | 0
rVT3 | PMU3_PT Turns Ratio : 1 | 2000.0 | 1.0 | 10000.0
rCT3 | PMU3_CT Turns Ratio : 1 | 600.0 | 1.0 | 5000.0
nVTA3 | PMU3_A phase Input Signal Name | A2 | 0 | 0
Update
Cancel
Cancel All

openECA Manager - DEVESH\Devesh Shukla

openECA Manager

Current Node: Default

Home | Devices | Adapters | Metadata | Monitoring | Alarms | Advanced

Trend Real-time Measurements

Refresh Interval: 2 sec Last Refresh: 10:06:43.068

StatusFlag Reference | Display Settings | Save Display Settings | Load Display Settings

- DIRECT CONNECTED
  - PMU1 Edit

	PMU1-DF	0
☐	PMU1-FQ	59.997 Hz
☐	PMU1-PA1	39.804 Degrees
☐	PMU1-PA2	35.131 Degrees
☑	PMU1-PM1	21680.732 Volts
☑	PMU1-PM2	772.875 Amps
	PMU1-QF	0
	PMU1-SF	00000000 Hex

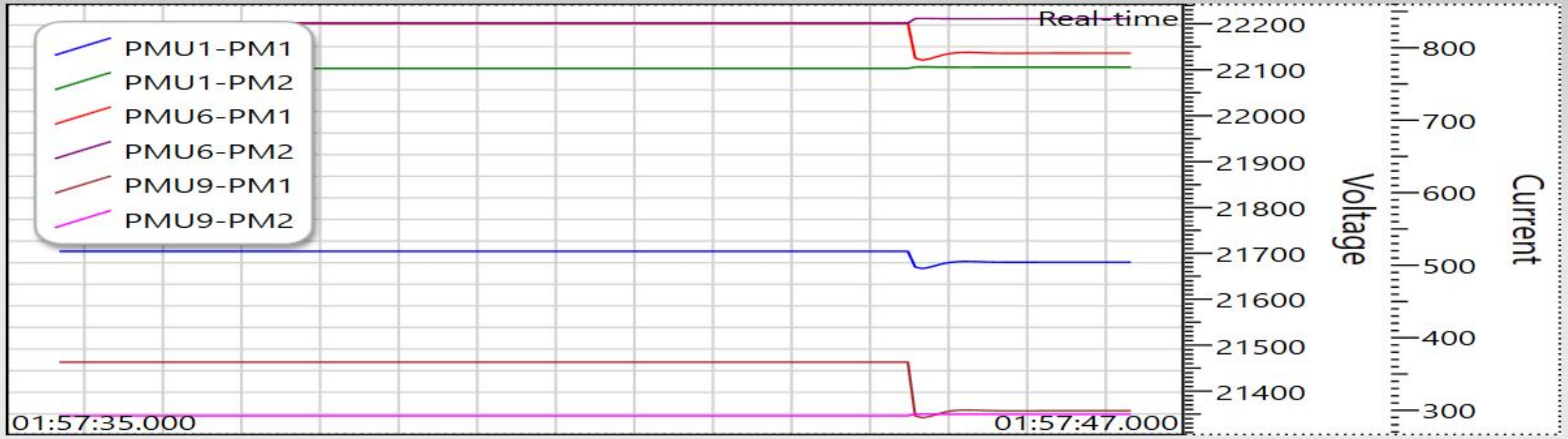
  - PMU6 Edit

	PMU6-DF	0
☐	PMU6-FQ	59.997 Hz
☐	PMU6-PA1	30.289 Degrees
☐	PMU6-PA2	-160.47 Degrees
☑	PMU6-PM1	22135.521 Volts
☑	PMU6-PM2	839.621 Amps
	PMU6-QF	0
	PMU6-SF	00000000 Hex

  - PMU9 Edit

	PMU9-DF	0
☐	PMU9-FQ	59.997 Hz
☐	PMU9-PA1	29.888 Degrees
☐	PMU9-PA2	-160.39 Degrees
☑	PMU9-PM1	21357.396 Volts
☑	PMU9-PM2	293.965 Amps
	PMU9-QF	0
	PMU9-SF	00000000 Hex

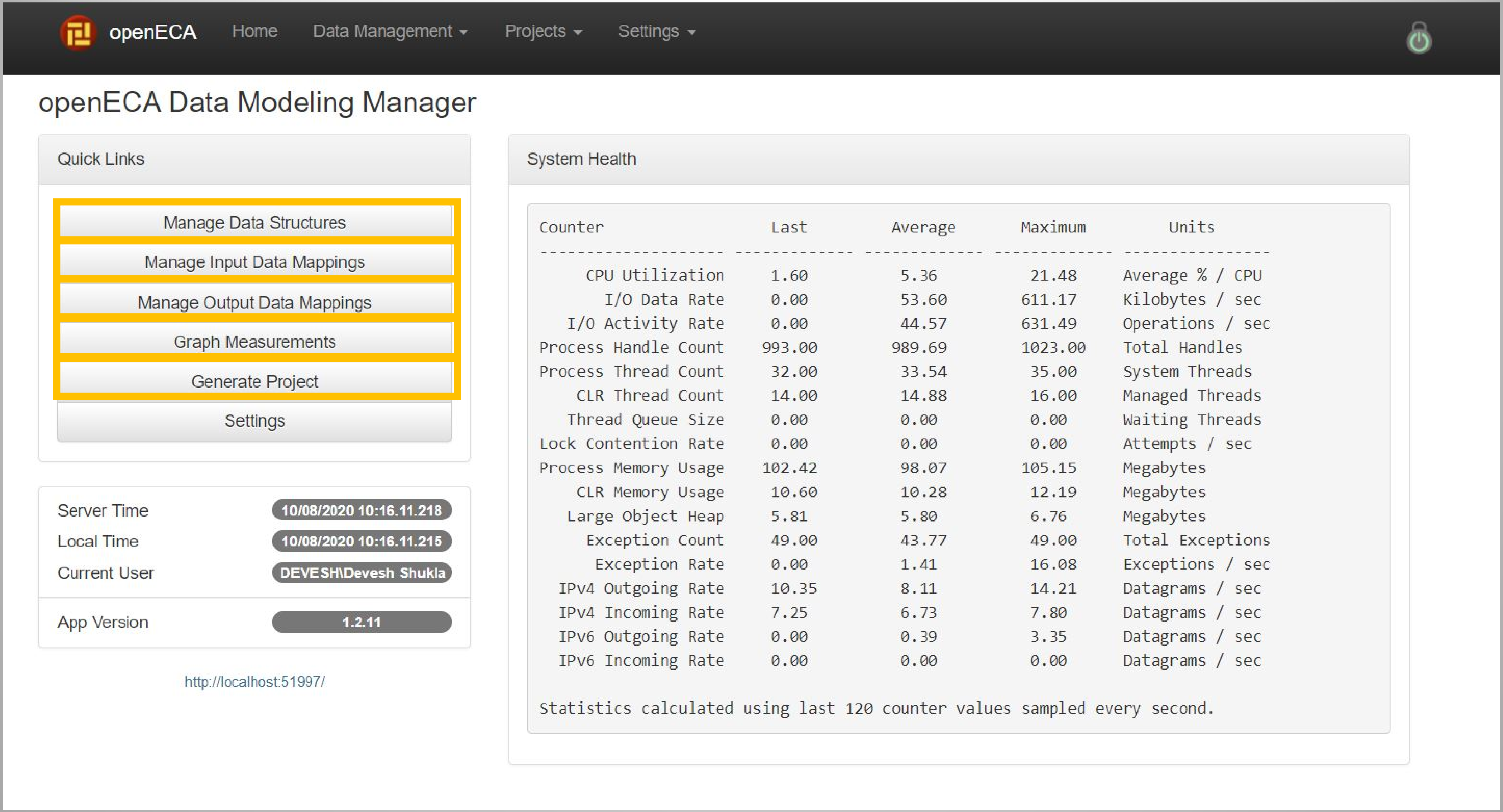
- CALCULATED

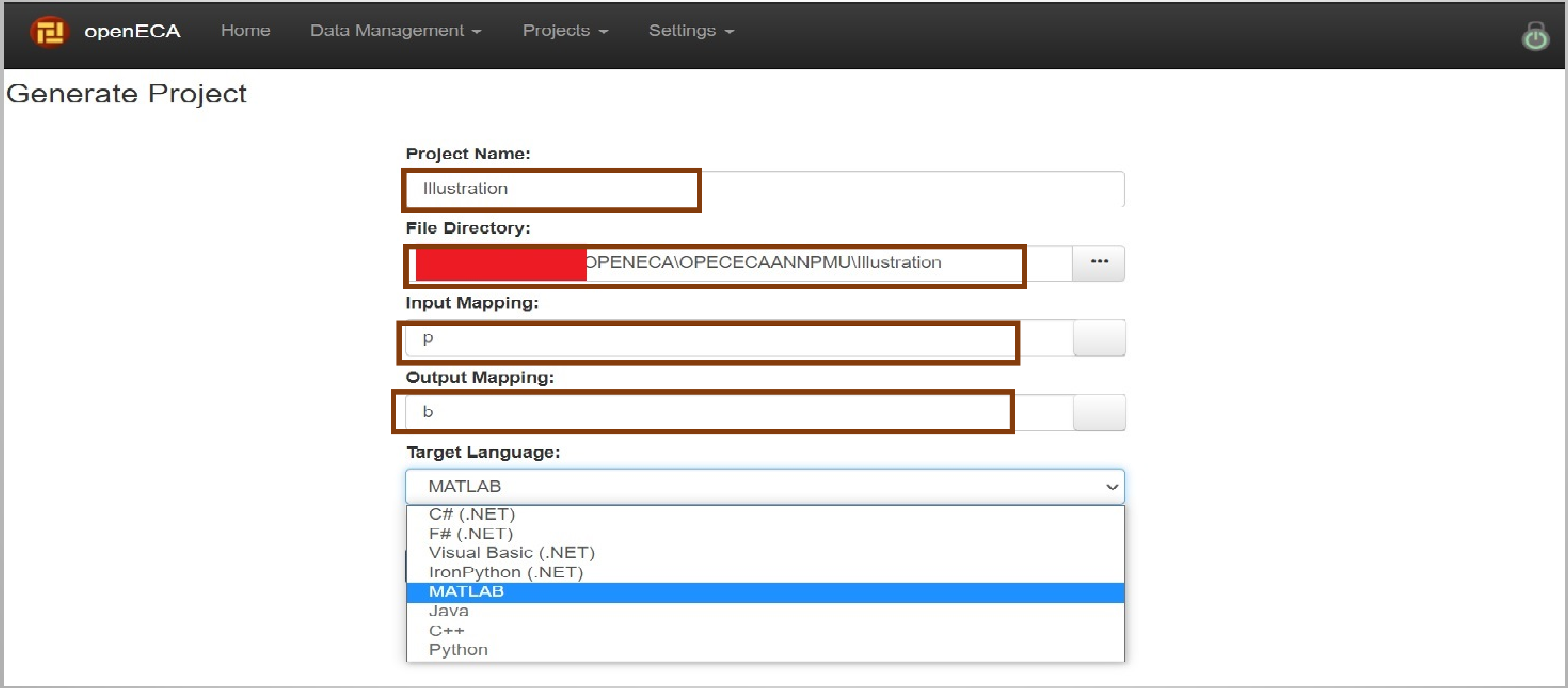


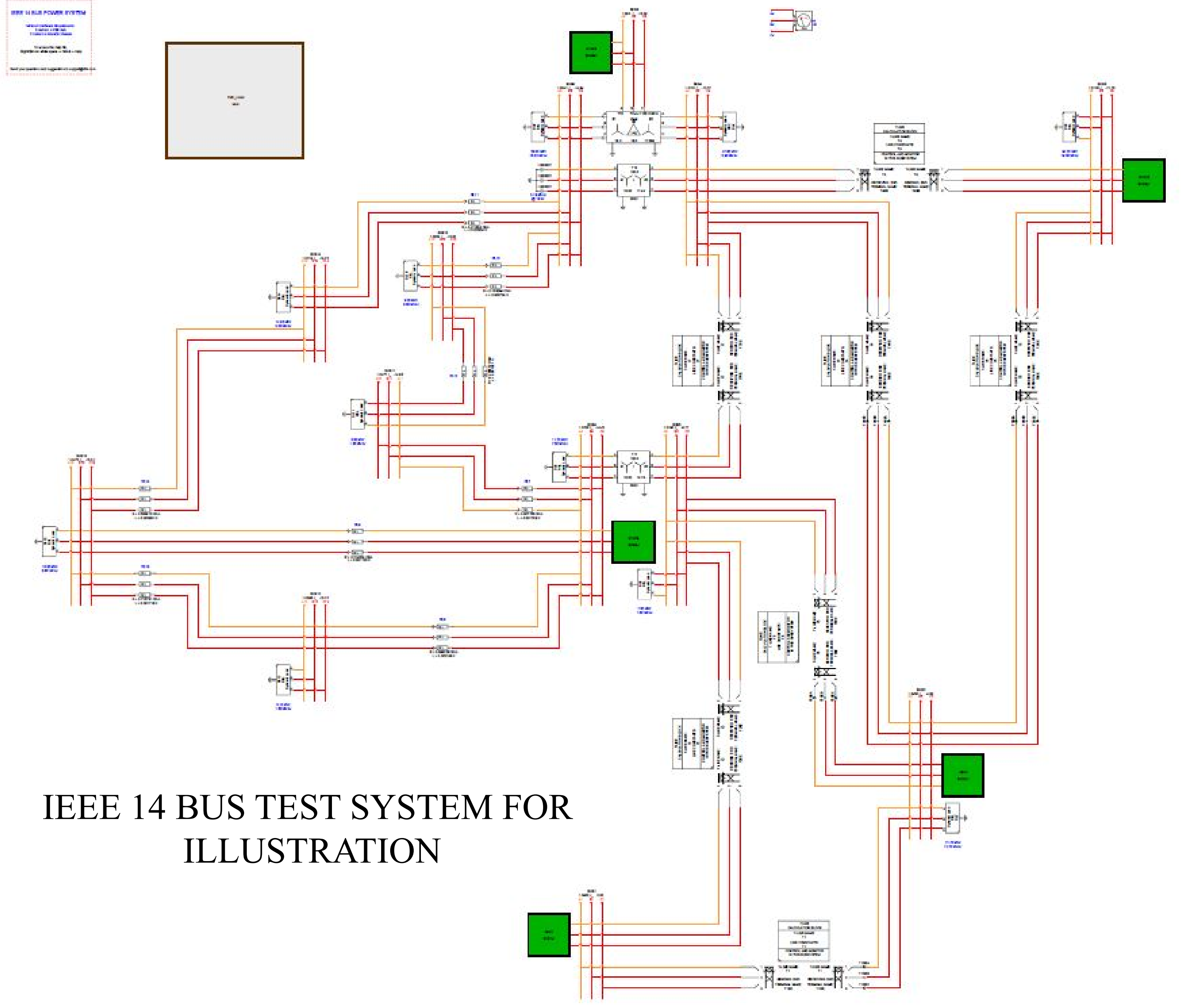
ID	Signal Reference	Time Tag	Value	Unit
PMU1:32	PMU1-PM1	01:57:47.000	21680.732	Volts
PMU1:34	PMU1-PM2	01:57:47.000	772.875	Amps
PMU6:75	PMU6-PM1	01:57:47.000	22135.521	Volts
PMU6:77	PMU6-PM2	01:57:47.000	839.621	Amps

Run-time Statistics: PMU1 Refresh Interval: 2 sec

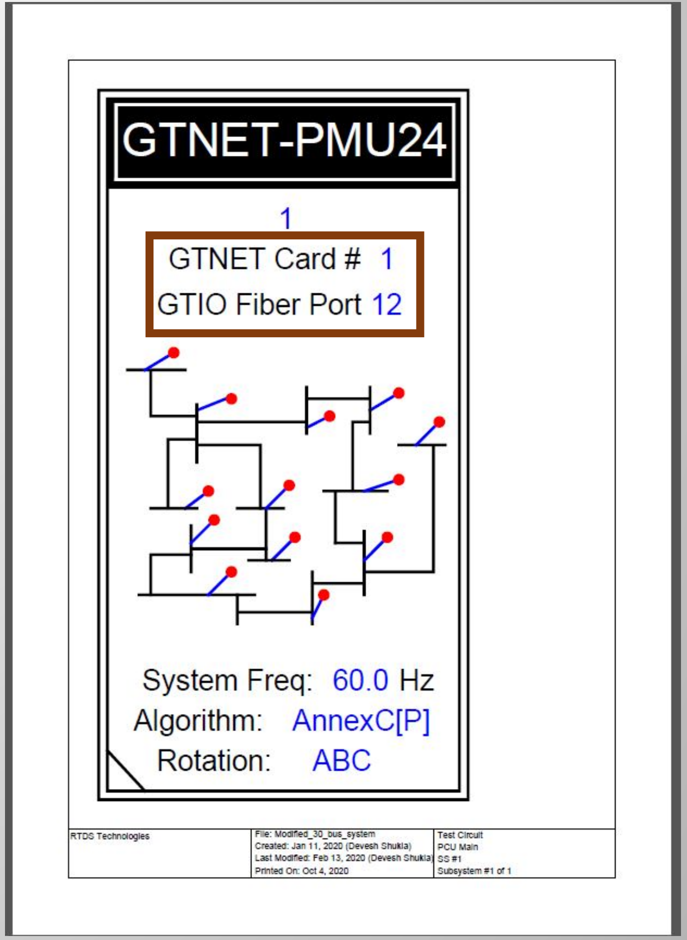
ID	Statistic	Value	TimeTag
STAT:37	Data Quality Errors	0	10:06:36.206
STAT:45	Last Report Time	57:38.999	10:06:36.206
STAT:38	Time Quality Errors	0	10:06:36.206
STAT:44	Total Frames	20	10:06:36.206
STAT:39	Device Errors	0	10:06:36.206
STAT:46	Missing Frames	0	10:06:36.206
STAT:40	Measurements Received	120	10:06:36.206
STAT:61	Missing Data	0	10:06:36.206
STAT:41	Measurements Expected	140	10:06:36.206


openECA
Home
Data Management
Projects
Settings
openECA Data Modeling Manager
Quick Links
Manage Data Structures
Manage Input Data Mappings
Manage Output Data Mappings
Graph Measurements
Generate Project
Settings
Server Time 10/08/2020 10:16.11.218
Local Time 10/08/2020 10:16.11.215
Current User DEVESH\Devesh Shukla
App Version 1.2.11
http://localhost:51997/
System Health
Counter Last Average Maximum Units
CPU Utilization 1.60 5.36 21.48 Average % / CPU
I/O Data Rate 0.00 53.60 611.17 Kilobytes / sec
I/O Activity Rate 0.00 44.57 631.49 Operations / sec
Process Handle Count 993.00 989.69 1023.00 Total Handles
Process Thread Count 32.00 33.54 35.00 System Threads
CLR Thread Count 14.00 14.88 16.00 Managed Threads
Thread Queue Size 0.00 0.00 0.00 Waiting Threads
Lock Contention Rate 0.00 0.00 0.00 Attempts / sec
Process Memory Usage 102.42 98.07 105.15 Megabytes
CLR Memory Usage 10.60 10.28 12.19 Megabytes
Large Object Heap 5.81 5.80 6.76 Megabytes
Exception Count 49.00 43.77 49.00 Total Exceptions
Exception Rate 0.00 1.41 16.08 Exceptions / sec
IPv4 Outgoing Rate 10.35 8.11 14.21 Datagrams / sec
IPv4 Incoming Rate 7.25 6.73 7.80 Datagrams / sec
IPv6 Outgoing Rate 0.00 0.39 3.35 Datagrams / sec
IPv6 Incoming Rate 0.00 0.00 0.00 Datagrams / sec
Statistics calculated using last 120 counter values sampled every second.

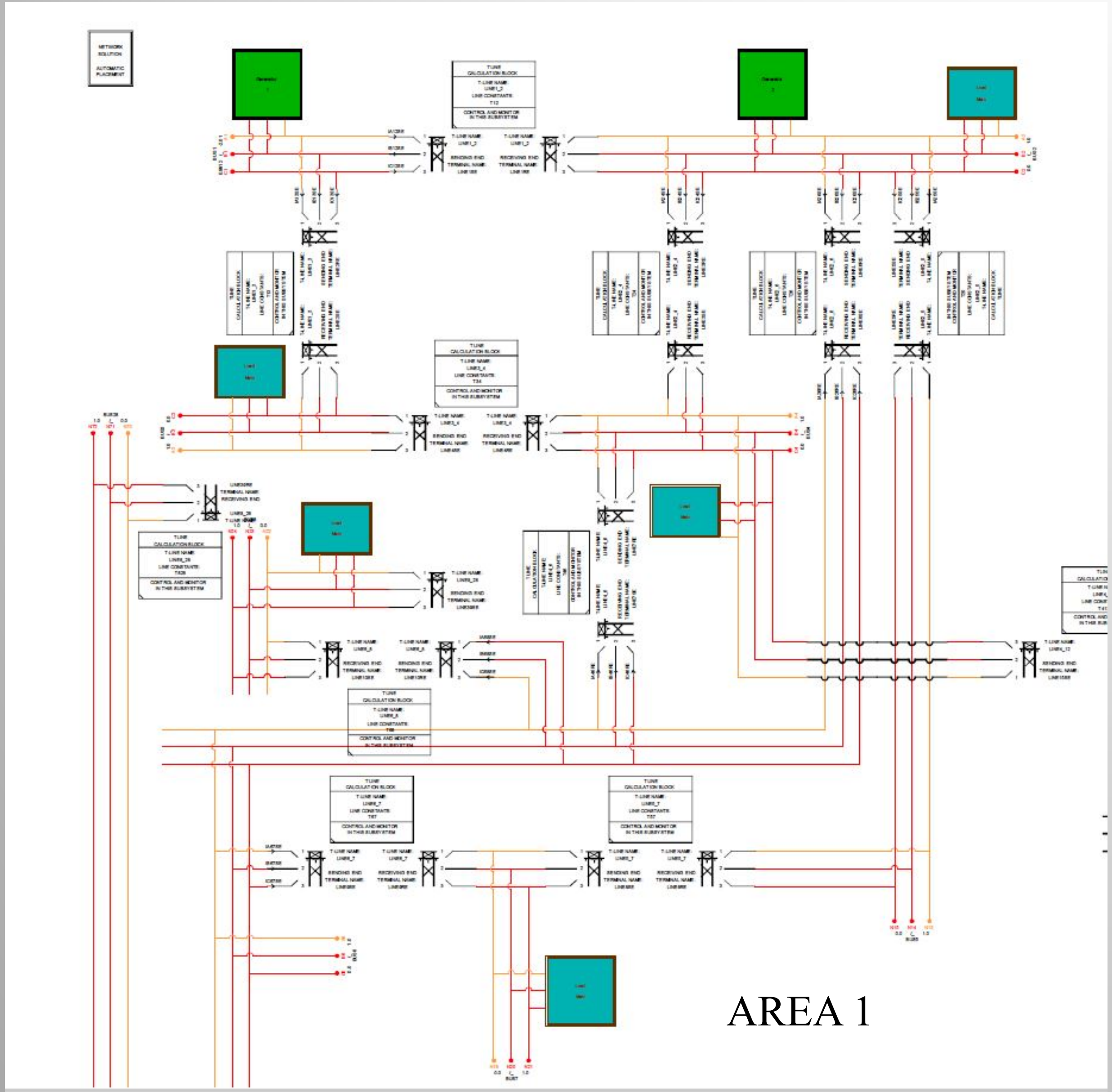

openECA
Home
Data Management
Projects
Settings
Generate Project
Project Name:
Illustration
File Directory:
OPENECA\OPECECAANNPMU\Illustration
...
Input Mapping:
p
Output Mapping:
b
Target Language:
MATLAB
C# (.NET)
F# (.NET)
Visual Basic (.NET)
IronPython (.NET)
MATLAB
Java
C++
Python



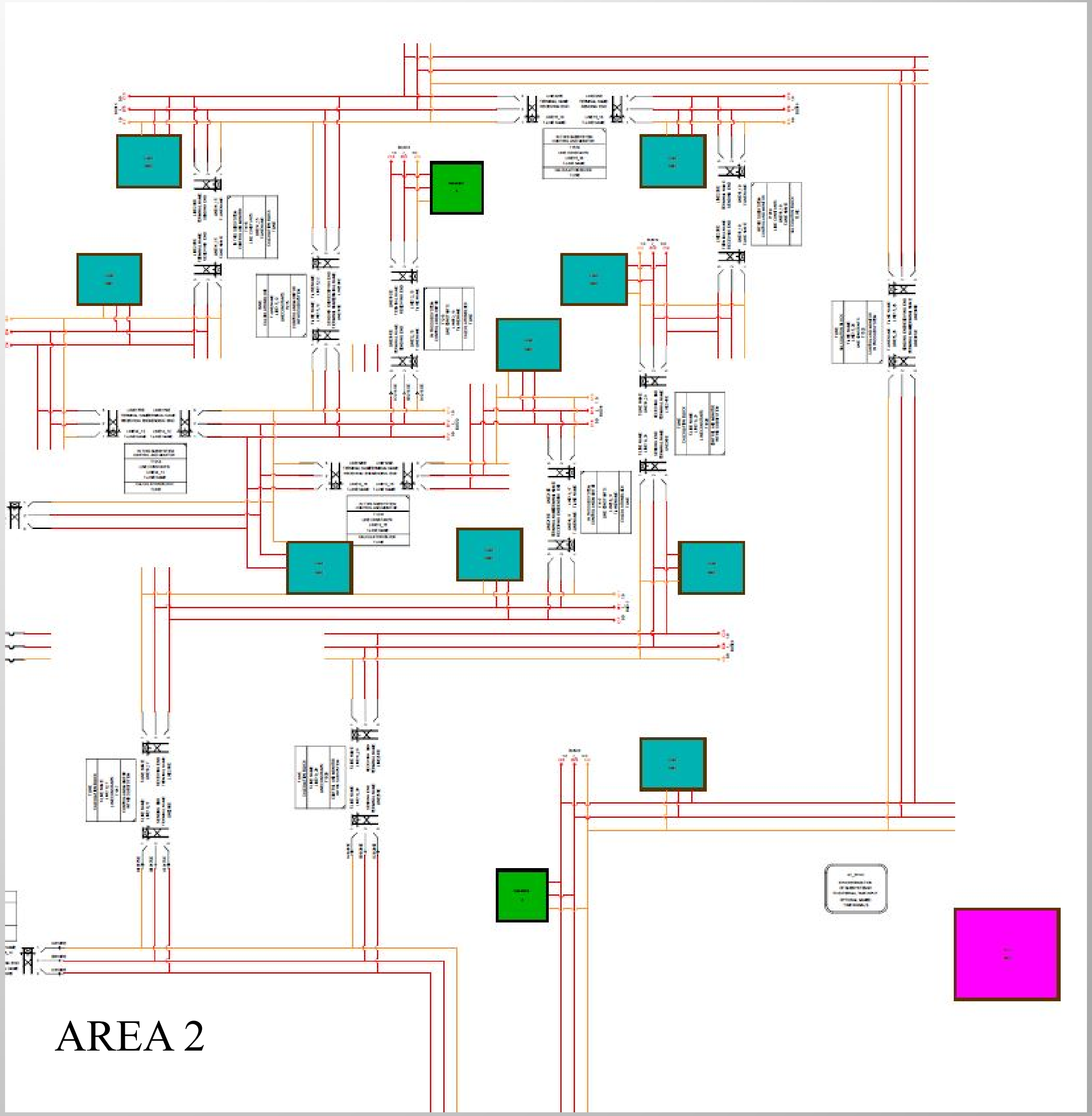
IEEE 14 BUS TEST SYSTEM FOR ILLUSTRATION



Real-Time Estimation of ATC:- Test Case

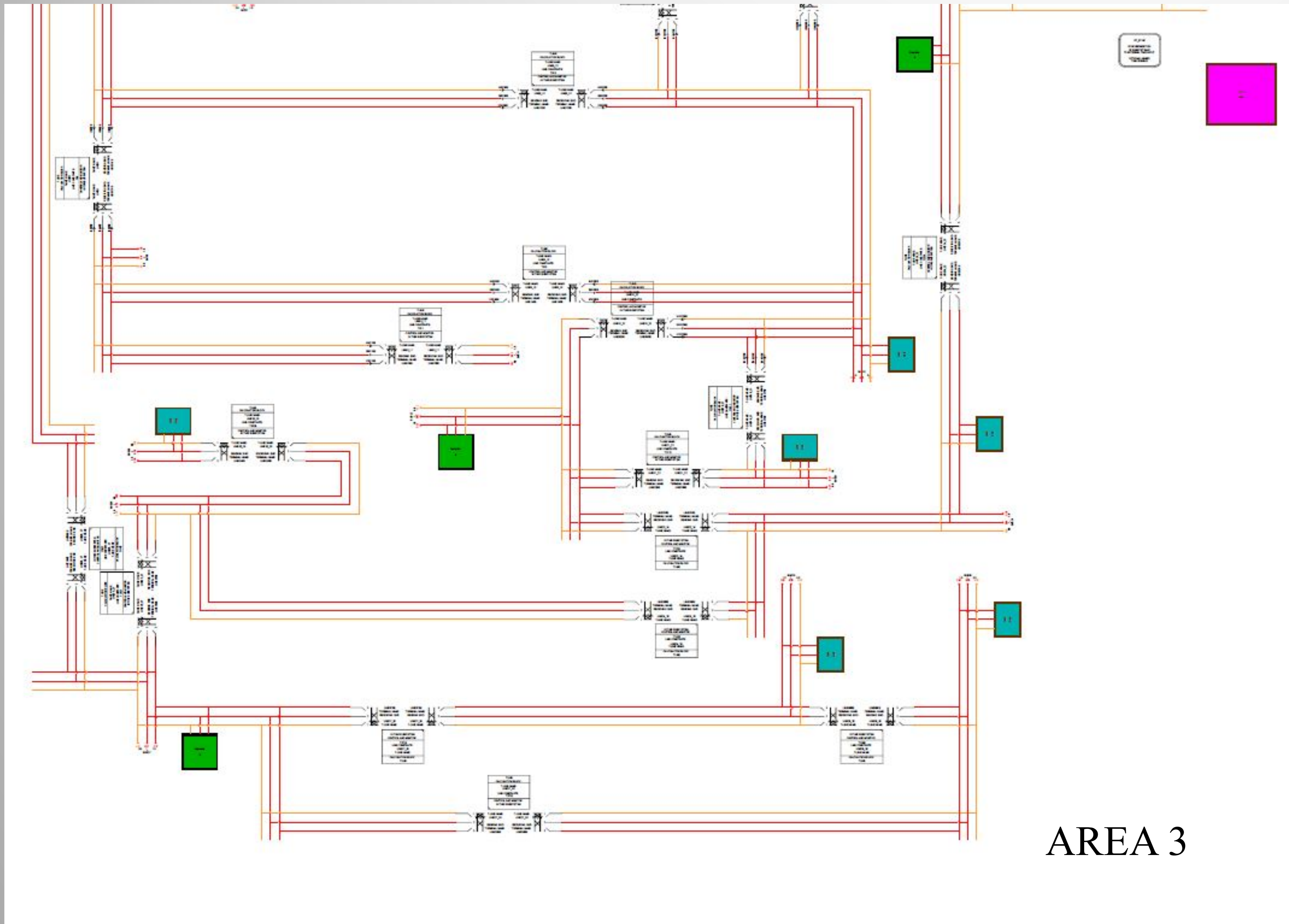


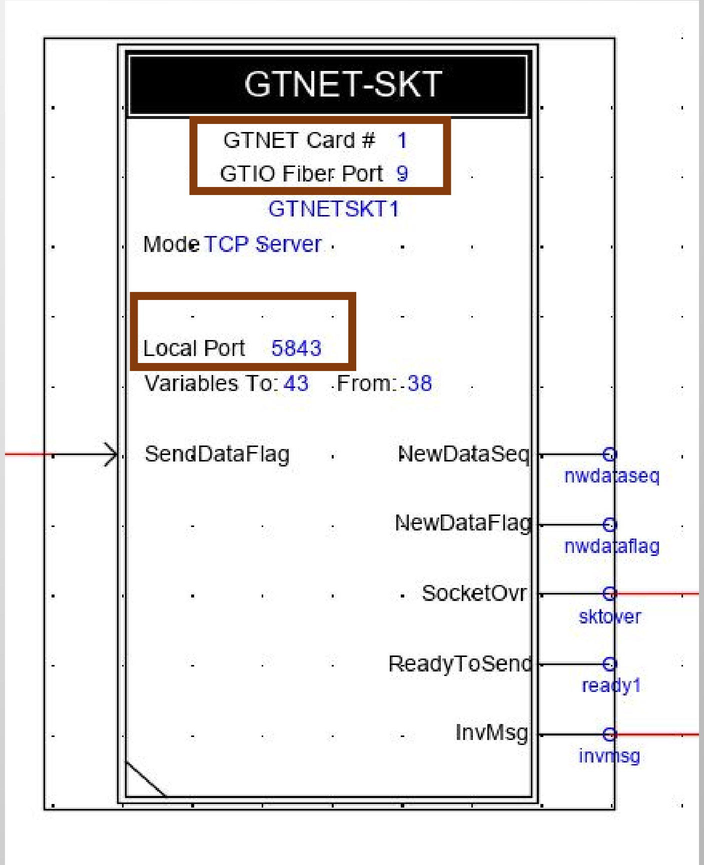
AREA 1



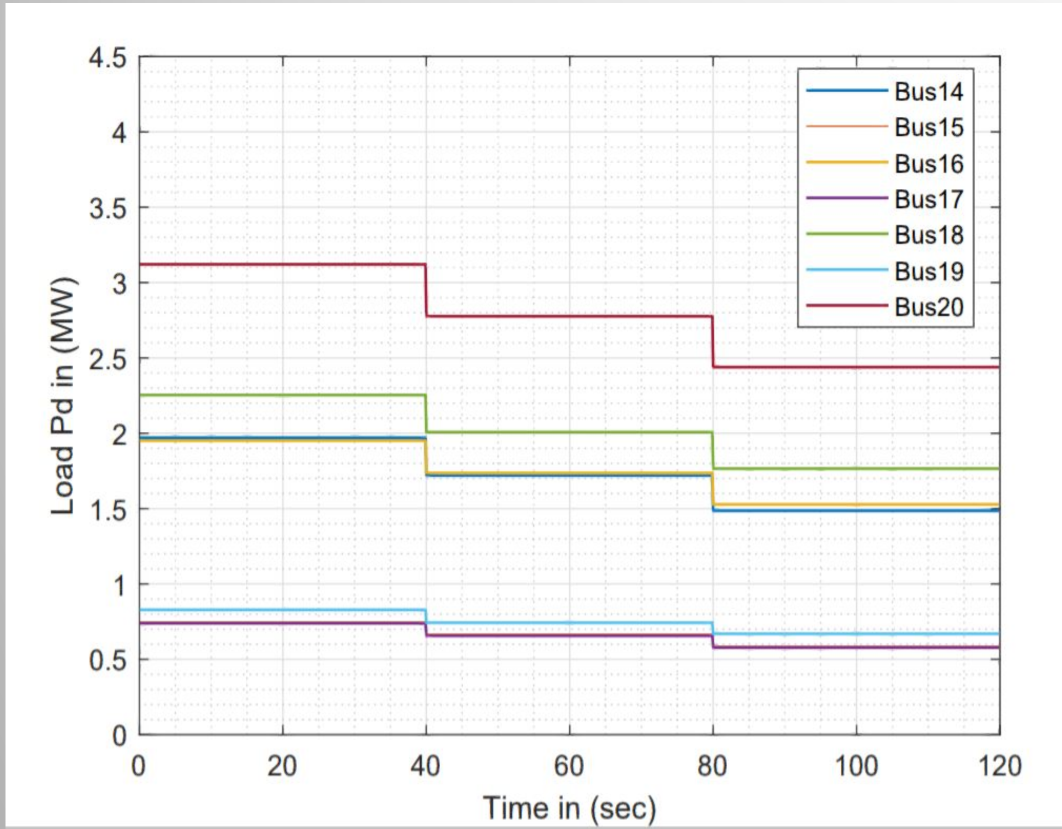
AREA 2

Real-Time Estimation of ATC:- Test Case

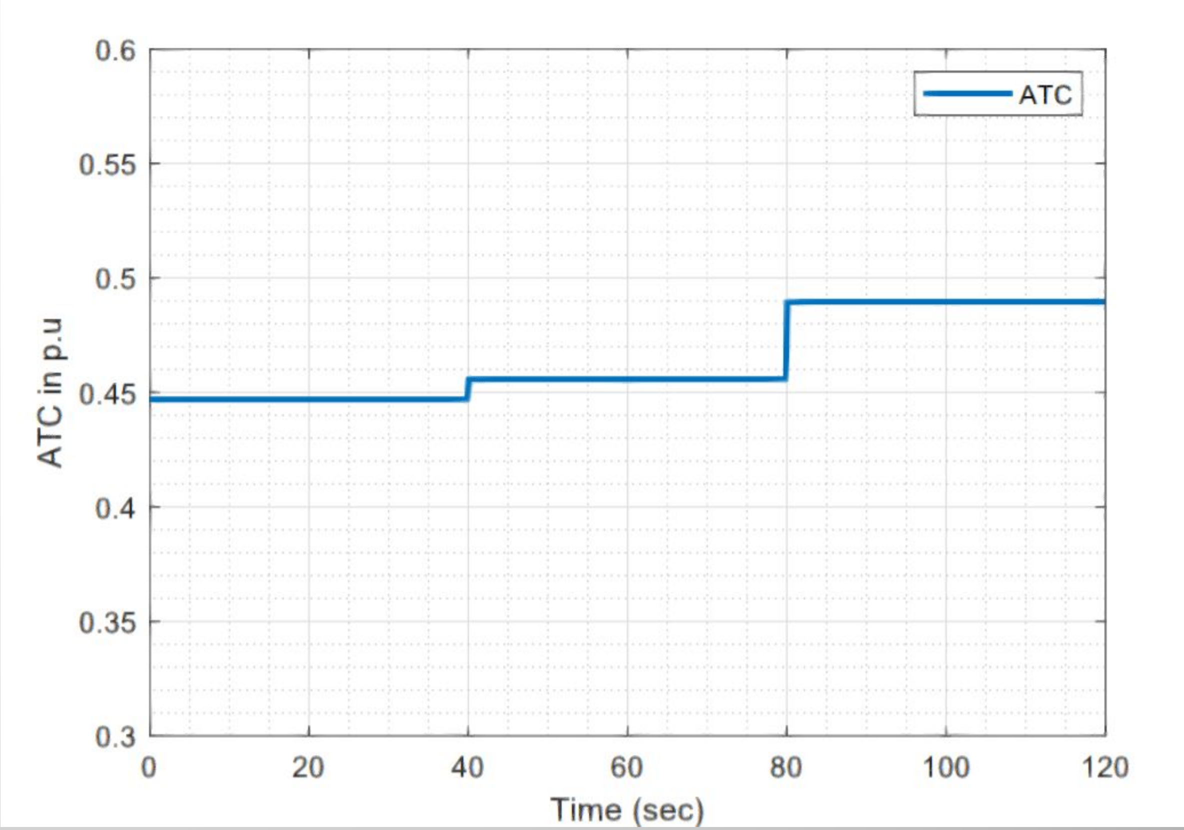




Results and Discussion : - Performance of Real Time ANN Estimator



(a)



(b)

- Figure XIV Estimated ATC and loading of buses in area A2 during RTDS simulation.

Thank You