

To the one and all.

LORD RAMA

卐 एकं सत् विप्र बहुत वदन्ति 卐

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TABLE OF CONTENTS

CERTIFICATE	v
DECLARATION BY THE CANDIDATE	vii
COPYRIGHT TRANSFER CERTIFICATE.....	ix
Acknowledgment	xi
Table of Contents.....	xiii
List of Figures	xix
List of Tables	xxvii
List of Abbreviations and Symbols.....	xxxix
Preface	xxxvii
Chapter 1 Introduction and Literature Review.....	1
1.1 A brief background and prevailing situation.	1
1.2 Literature Review.....	5
1.2.1 Available Transfer Capability	5
1.2.2 Integrated Transmission and Distribution	10
1.2.3 Conservation Voltage Reduction (CVR)	13
1.2.4 Available Distribution Capability.....	14
1.2.5 Blockchain.....	14
1.3 Research gap and motivation	15
1.4 Thesis Organization.....	17
1.5 Conclusion.....	18
Chapter 2 Available Transfer Capability Assessment and Enhancement.....	19
2.1 Introduction	19
2.2 Definition of ATC and related terminology.....	19
2.2.1 Total Transfer Capability (TTC).....	20
2.2.2 First Contingency Incremental Total Transfer Capability (FCITTC)	21
2.2.3 First Contingency Total Transfer Capability (FCTTC).....	21
2.2.4 Simultaneous and Non-Simultaneous transfer capability	21
2.3 Assessment of transfer capability.....	22
2.3.1 Transient Reliability Margin (TRM)	24
2.3.2 Capacity Benefit Margin (CBM)	24
2.4 Offline Assessment of Available Transfer Capability using Pattern Search Optimization	25
2.4.1 Problem Formulation: - ATC Assessment	25
2.4.2 Solution Methodology	27

2.4.3	Patter Search Optimization	28
2.4.4	Case Study	33
2.5	Enhancement of Available Transfer Capability	41
2.5.1	Modeling of FACTS Devices	42
2.5.2	RENEWABLE SOURCE MODELLING: - MODELLING OF SOLAR PV.....	44
2.5.3	Problem Formulation: - ATC Determination and Enhancement	46
2.5.4	Solution Methodology	50
2.5.5	Case Study	53
2.6	Conclusion	56
Chapter 3 Pseudo PMU for Quasi-Static Analysis of Power System and near real-time load forecasting		59
3.1	Introduction.....	59
3.2	PSEUDO PMU AND PHASOR MEASUREMENT UNITS	60
3.3	Methodology For Implementing Pseudo Pmu	61
3.3.1	Input Data.....	61
3.3.2	Solution of Power Flow Equations.....	62
3.3.3	Pseudo-PMU Emulation.....	64
3.3.4	Voltage and current Extraction	64
3.3.5	PMU PLACEMENT	69
3.3.6	CASE STUDY	71
3.4	Near real-time load forecasting.....	75
3.4.1	Data conditioning and pre-processing	76
3.4.2	SVR based method for load forecasting.	76
3.4.3	Proposed Models.....	78
3.4.4	Evaluation and Test Results.....	81
3.5	Conclusion	91
Chapter 4 Real-Time Estimation of ATC using PMU data and ANN		93
4.1	Introduction.....	93
4.2	Offline ATC evaluation and training data generation.....	94
4.3	Linear State Estimator	96
4.3.1	Formation of \mathcal{H} matrix.....	96
4.4	Real-Time Estimation of ATC using ANN	99
4.4.1	Radial basis function neural network.....	99
4.4.2	ANN architecture.....	100
4.4.3	Feature Extraction	102
4.4.4	Testing	102

4.5	Implementation of the method.....	104
4.6	Authentication in real-time simulation using RTDS.....	106
4.7	Case Study.....	108
4.7.1	Description of Test System	108
4.7.2	Result and Discussion	110
4.7.3	Modified IEEE 30-bus test system:	115
4.7.4	Modified IEEE 118 bus test system:.....	118
4.7.5	Performance of ANN based estimator:.....	119
4.7.6	Real Time Authentication of IEEE 30 bus test system using RTDS:.....	121
4.7.7	ATC and Dynamic ATC:.....	123
4.8	Conclusion.....	123
Chapter 5 ATC assessment and enhancement of integrated transmission and distribution system considering the impact of active distribution network.....		125
5.1	Introduction	125
5.2	ITD Framework.....	127
5.3	Modeling of ITD & DER	130
5.4	ATC & CVR: a brief overview.....	134
5.4.1	ATC.....	134
5.4.2	CVR.....	135
5.4.3	Load model impact	136
5.5	Problem formulation: ADN impact on ATC.....	136
5.5.1	ATC: transmission level.....	137
5.5.2	CVR: distribution level	139
5.5.3	Combined transmission & distribution: ITD objective.....	141
5.5.4	Optimization technique	141
5.6	Implementation of the proposed method.....	141
5.6.1	Functioning of MAS.....	142
5.6.2	Solution methodology	144
5.7	Case study: results and discussion.....	146
5.7.1	Description of the test system.....	146
5.7.2	Results and inferences	150
5.8	Conclusion.....	163
Chapter 6 Aggregated effect of Active Distribution System on Available Transfer Capability using Multi-Agent System based ITD framework.....		165
6.1	INTRODUCTION.....	165
6.2	MAS BASED ITD FRAMEWORK.....	167

6.2.1	<i>pcc Node</i>	168
6.2.2	Multi-Agent based System	168
6.2.3	Interface Architecture	170
6.2.4	System components modeling	170
6.2.5	ADS Component Modelling	172
6.3	PROBLEM FORMULATION	174
6.3.2	IMPLEMENTATION OF THE PROPOSED METHOD.....	178
6.4	PROPOSED INDICES FOR IMPACT ASSESSMENT OF ADS ON ATC	185
6.4.1	<i>ATCEfactor</i>	185
6.4.2	<i>ATCVRfactor</i>	186
6.5	RESULT AND DISCUSSION	186
6.5.1	Test System.....	186
6.5.2	Results	188
6.5.3	Inferences.....	192
6.6	CONCLUSION	194
Chapter 7	Block-Chain and its impact on Aggregated Load Profile and Available Distribution Capability	197
7.1	Introduction.....	197
7.2	Block-Chain Technology Implementation	198
7.3	Techno-economic operation of ADN using the blockchain-based framework.....	200
7.3.1	LMCP and LMCV determination: -	203
7.4	Available Distribution Capability, Aggregated load profile & Loadability margin.....	206
7.5	ADN Component Modelling	207
7.5.1	Electric Vehicles and their Charging	207
7.5.2	Modeling of DER.....	208
7.6	Problem formulation of DSO	210
7.6.1	Loss Minimization	210
7.6.2	ADC Evaluation	212
7.6.3	Blockchain Efficiency Factor (<i>BCef</i>).....	212
7.6.4	Solution Methodology	213
7.7	Result Analysis And Discussion.....	213
7.8	Conclusion	223
Chapter 8	Conclusion and Future Scope	225
8.1	Conclusion	225
8.2	Future Scope.....	227
Reference	229

A. Appendix: Publication in referred and peer-reviewed Journals.....	241
B. Appendix: Publication in national/international conferences.....	243

LIST OF FIGURES

Figure 1.1 Schematic representation of power flow variation due to renewable source.	2
Figure 1.2 Changing scenario of T&D systems.	3
Figure 1.3 Restructuring of Transportation Sector And its impact on power grids.	4
Figure 1.4 Schematic representation of various aspects for which the existing literature review has been given.....	5
Figure 1.5 Different methods for ATC assessment.	6
Figure 1.6 Schematic representation of different sections identified during literature review as research gap to be tackled.	16
Figure 2.1 Illustration of (a) ATC TTC and R.M (b) Significance of ATC.....	23
Figure 2.2 Flow Chart illustrating the solution methodology	28
Figure 2.3 Pattern Search Optimization Process	32
Figure 2.4 Modified IEEE 24 BUS System.....	33
Figure 2.5 Modified IEEE 30 Bus Test System	37
Figure 2.6 Convergence for transfer from area 1 to 2 with slack bus limited by Five times of <i>Pmax</i>	39
Figure 2.7 Convergence for transfer from area 1 to 2 with slack bus limited by <i>Pmax</i>	39
Figure 2.8 Convergence for transfer from area 3 to 2 with slack bus limited by <i>Pmax</i> .	40
Figure 2.9 Convergence for transfer from area 3 to 2 with slack bus limited by Five times its <i>Pmax</i>	40

Figure 2.10 Schematic representation of TCSC modeling.....	42
Figure 2.11 Diagrammatic illustration of SVC modeling.....	43
Figure 2.12 Schematic representation of a proposed method for ATC assessment and enhancement.....	50
Figure 2.13 Flowchart showing the various steps of the solution process.....	50
Figure 2.14 Modified IEEE 24 BUS RTS test system.....	53
Figure 2.15 I-V characteristic of considered solar panels for different S and TA	54
Figure 3.1 Block Diagram representation of proposed methodology.....	62
Figure 3.2 PMU DATA STORAGE LAYOUT.....	67
Figure 3.3 Schematic comparison of iterative and PPMU algorithm.....	68
Figure 3.4 Plot of current obtained by PMU 1 at bus 2.....	72
Figure 3.5 Plot of Voltage obtained by PMU 1 at bus 2.....	72
Figure 3.6 Plot of current obtained by PMU 2 at bus 3.....	72
Figure 3.7 Plot of Voltage obtained by PMU 2 at bus 3.....	73
Figure 3.8 Plot of current obtained by PMU 3 at bus 8.....	73
Figure 3.9 Plot of Voltage obtained by PMU 3 at bus 8.....	73
Figure 3.10 Schematic representation of data pre-processing stage.....	76
Figure 3.11 Schematic representation of input features.....	78
Figure 3.12 Flow chart showing the implementation of the proposed method.....	80
Figure 3.13 Plot for Mar 22, 2017 (weekday).....	81

Figure 3.14 Plot for Apr 4 (Holiday).....	82
Figure 3.15 Plot for Mar 25, 2017 (Saturday).....	82
Figure 3.16 Plot for Mar 22, 2017 (weekday).....	83
Figure 3.17 Plot for Mar 25, 2017 (Sunday).....	83
Figure 3.18 Plot for Apr 4 (Holiday).....	84
Figure 3.19 Plot for Mar 25, 2017 (Saturday).....	84
Figure 4.1 Schematic Representation of ATC evaluation.....	94
Figure 4.2 Flowchart of offline ATC evaluation and training data generation.....	95
Figure 4.3 Illustrative example showing three buses connected to a PMU bus.....	97
Figure 4.4 RBF architecture Proposed.....	101
Figure 4.5 Schematic Representation for Feature Extraction.....	104
Figure 4.6 Software-based development of the proposed method.....	105
Figure 4.7 Practical Implementation layout of the proposed method.....	105
Figure 4.8 Pictorial illustration of the process used in authentication in RTDS simulation.	107
Figure 4.9 Data Archived by PMU at bus 2.....	112
Figure 4.10 IEEE 24 bus test system Emulation Results.....	113
Figure 4.11 Plot of convergence for ATC evaluation of IEEE 30 bus test system from area 1 to area 2.....	116
Figure 4.12 PMU emulation for IEEE 30 bus Test System.....	116

Figure 4.13 a. ATC estimated using ANN estimator for Transaction from Area 1 to Area 2 of IEEE 30-Bus system; b. Error Histogram of ATC estimator using reduced features for IEEE 30 Bus System.....	117
Figure 4.14 a. ATC estimated using ANN estimator for Transaction from Area 1 to Area 2 of IEEE 118-Bus system; b. Error Histogram of ATC estimator using reduced features for IEEE 118 Bus System.....	118
Figure 4.15 Estimated ATC and loading of buses in area A2 during RTDS simulation.	122
Figure 5.1 Integrated Transmission and Distribution Framework.	128
Figure 5.2 Diagrammatic representation of aggregated Model of T&D System.	133
Figure 5.3 Schematic representation of MAS functioning in ITD implementation.	142
Figure 5.4 Algorithm flowchart for an implementation of the proposed method.	145
Figure 5.5 RTS 24 BUS Test System.....	148
Figure 5.6 Modified IEEE 123 bus distribution test Feeder.....	149
Figure 5.7 Convergence of pattern search optimization.....	152
Figure 5.8 Convergence of particle swarm optimization.	153
Figure 5.9 ATC variation for 24 h under various cases.	155
Figure 5.10 Minimum, maximum, and mean ATC value of different % <i>ADN_{LOAD}</i>	157
Figure 5.11 Minimum Voltage Profile of ADN for (a). Case1(000) and Case2(100) (b). Case3(010) and Case4(110) (c). Case5(001) and Case6(101) (d). Case7(011) and Case8(111).....	157

Figure 5.12 CVR Saving in percentage for different cases.....	158
Figure 5.13 Quasi-static variation of a total load of ADN in the sink area.....	159
Figure 5.14 Hourly ATC (MW) for different % ADN_{load} of different cases without considering the effect of CVR (a) Hourly ATC (MW) for different % ADN_{load} without DER, (b) Hourly ATC (MW) for different % ADN_{load} with PV DER, (c) Hourly ATC (MW) for different % ADN_{load} WIND DER (d) Hourly ATC (MW) for different % ADN_{load} with PV & WIND DER	161
Figure 5.15 Hourly ATC (MW) for different % ADN_{load} of different cases considering the effect of CVR (a) Hourly ATC (MW) for different % ADN_{load} without DER, (b) Hourly ATC (MW) for different % ADN_{load} with PV DER, (c) Hourly ATC (MW) for different % ADN_{load} WIND DER, (d) Hourly ATC (MW) for different % ADN_{load} with PV & WIND DER.....	162
Figure 6.1 MAS ITD framework.....	169
Figure 6.2 Schematic representation of aggregated ITD System.....	171
Figure 6.3 Taxonomy of Agents Vectors	178
Figure 6.4 TSO and DSO interaction via MAS through Agentware	182
Figure 6.5 Flowchart of the solution process	183
Figure 6.6 Single line representation of the considered test systems.	187
Figure 6.7 Surface plot of ATC for 24 hours at a resolution of 15 minutes.....	189
Figure 6.8 Box-plot of ATC at different % ADS_{load} loading for various cases.....	190
Figure 6.9 Variation of ATC throughout the day for different % ADS_{load}	191

Figure 6.10 Minimum, Mean and Maximum values of the ATC for various cases at (a) 2 % ADS_{load} (b) 10 % ADS_{load} and (c) 20 % ADS_{load}	191
Figure 6.11 $ATCVR_{factor}$ and $ATCE_{factor}$ plots for 24 hours.....	192
Figure 7.1 Schematic illustration of Blockchain implementation through the python interface.	198
Figure 7.2 Ganache Interface	199
Figure 7.3 Schematic illustration of the interaction between various components of the smart grid.....	199
Figure 7.4 The changing technologies and their impact: - schematic representation. .	202
Figure 7.5 Schematic representation of blockchain implementation in ADN.	202
Figure 7.6 Sequential bid submission process on the block-chain.....	204
Figure 7.7 Flow chart for energy transaction scheduling and settlement process.....	204
Figure 7.8 Test System: Modified IEEE 123 bus feeder.....	214
Figure 7.9 Load Margin plot for various cases of Modified IEEE 24 bus test system	215
Figure 7.10 ADC of ADN at resolution of 15 min for 24 hrs.	216
Figure 7.11 Aggregated Load Profile of ADN at resolution of 15 min for 24 hrs.....	217
Figure 7.12 Illustration of LMCP determination.....	218
Figure 7.13 LMCP of ADN at a resolution of 15 min for 24 hrs.	218
Figure 7.14 PV power deviation of ADN at a resolution of 15 min for 24 hrs.....	219
Figure 7.15 Wind power deviation of ADN at resolution of 15 min for 24 hrs.....	219

Figure 7.16 Losses of ADN at a resolution of 15 min for 24 hrs.	220
Figure 7.17 BCef factor of ADN at resolution of 15 min for 24 hrs.....	220
Figure 7.18 Clock plot showing the CS1 power demand over 24 hrs.	221
Figure 7.19 Clock plot showing the CS2 power demand over 24 hrs.	221

LIST OF TABLES

Table 1.1 CLASSIFICATION DEPENDING ON NATURE OF APPLICATION	9
Table 2.1 Areas in IEEE 24 Bus System	34
Table 2.2 Tie Lines	34
Table 2.3 Additional Generator Added into the system	34
Table 2.4 TTC OBTAINED USING PROPOSED METHOD FROM AREA 1 TO 2..	35
Table 2.5 ATC FOR TRANSACTION FROM AREA 1 TO 2 FOR RTS	35
Table 2.6 COMPARISION OF RESULTS OBTAINED FROM PROPOSED METHOD AND TSCOPF	36
Table 2.7 COMPARISION OF PROPOSED METHOD AND TSCOPF	36
Table 2.8 AREAS IN MODIFIED IEEE 30 BUS.....	38
Table 2.9 TIE LINES IN IEEE 30 BUS SYSTEM	38
Table 2.10 PV panel parameters.....	54
Table 2.11 SET of Credible Contingencies	54
Table 2.12 ATC for Transaction from A1 to A2.....	55
Table 3.1 OPTIMAL PLACEMENT OF PMU IN IEEE 24-BUS RTS SYSTEM.	71
Table 3.2 Comparison of Iterative and PPMU algorithm using MATLAB 17b on intel i7 processor.....	74
Table 3.3 COMPARISION OF ERRORS FOR DIFFERENT TYPES OF DAYS.	84
Table 3.4 Finding the most unstable time of the day.	85

Table 3.5 Comparison of Holiday model with simple SVR model.....	86
Table 3.6 Comparison of weekend model with simple SVR model.	87
Table 3.7 Error Range for SVR Model.	87
Table 3.8 SVR MODEL ABSOLUTE ERROR PERCENTAGE FOR 10 WEEKS.	87
Table 3.9 SVR weekly window errors for 42 weeks consecutively.....	88
Table 3.10 Comparison of prediction performance of all the three proposed models. ..	89
Table 3.11 MODEL 1 ABSOLUTE ERROR PERCENTAGE FOR 10 WEEKS.....	90
Table 3.12 MODEL 2 ABSOLUTE ERROR PERCENTAGE FOR 10 WEEKS.....	90
Table 4.1 Structure Field and accessing method of PMU.....	99
Table 4.2 Structure Field and accessing method of <i>PMU(id).x</i>	99
Table 4.3 Structure Field and accessing method of PMU(id).z1.	99
Table 4.4 SFA Algorithm for Feature Extraction.....	103
Table 4.5 Description of the test system.	109
Table 4.6 Details of Test Cases Under Consideration (Base Case).	109
Table 4.7 Reduced Features for different test cases using SFA.....	110
Table 4.8 Comparison of results obtained from TSCOPF and Proposed Method.	111
Table 4.9 Condition of source and sink areas of the 30-bus test system.....	115
Table 4.10 Performance of ANN estimator.....	119
Table 4.11 Training Time and Data Generation Time	120
Table 4.12 Offline Training and Testing Time.	120

Table 4.13 Real Time Implementation on RTDS.....	121
Table 4.14 Comparison of Proposed Method with the Referred Methods.....	122
Table 5.1 Implementation algorithm of MAS system.....	143
Table 5.2 Description of the test system	147
Table 5.3 Description of DERs considered in ADN (Modified IEEE 123).....	150
Table 5.4 Comparison of pattern search and PSO technique.	152
Table 5.5 Results illustrating the effect of considering the FACTS devices on the ATC of the system.	154
Table 5.6 ATC under various cases at 12:00 pm peak load time for 5 % ADNload	155
Table 5.7 Minimum, maximum, and mean values of ATC.....	160
Table 6.1 Implementation Algorithm	179
Table 6.2 Test cases that have been analyzed.	184
Table 6.3 Description of DS components.....	188
Table 7.1 Steps for obtaining the LMCP and LMCV	205
Table 7.2 EVagent taxonomy.	209
Table 7.3 Structure Field and their details for Charging Station (CSAgent).	209
Table 7.4 Various Cases considered for the analysis.	214
Table 7.5 Bid and actual value of Power (kW) and Price (INR/kW).....	222
Table 0.1 Publication from thesis' work.	241
Table 0.2 Publication from work done other than the thesis.....	242

Table 0.3 Publication in national/international conferences. 243

LIST OF ABBREVIATIONS AND SYMBOLS

Ld	Be the set representing all the load buses in the system.
n_{sink}	Number of load buses in sink area.
l	Subset of Ld representing all the load buses in the sink area.
s	Subset of Gen representing gen buses in source area.
x_i	Load at i^{th} bus.
x_{oi}	Initial load at i^{th} bus.
x_{min}	Lower limit of the variable.
φ_i	Represents pattern set.
φ_i^l	Represents i^{th} pattern vector of pattern set.
φ_i'	Represents transpose of φ_i .
ζ	Mesh Size.
P_{gi}	Active Power injected at i^{th} bus.
P_{di}	Active Power drawn at i^{th} bus.
Q_{gi}	Reactive Power injected at i^{th} bus.
Q_{di}	Reactive Power drawn at i^{th} bus.
P_{ij}	Power flowing in line connecting buses i, j .
P_{ij}^{max}	Maximum permissible power flow through line connecting buses i, j .
Q_{gi}^{max}	Upper limit of reactive power generation of i^{th} generator.
Q_{gi}^{min}	Lower limit of reactive power generation of i^{th} generator.
V_i	Voltage of i^{th} bus.
V_i^{min}	Lower limit of voltage permissible at i^{th} bus.

V_i^{max}	Upper limit of voltage permissible at i^{th} bus.
N	Total number of bus in the system.
M	Total number of generator buses.
L	Total number of lines.
TTC	Total Transfer Capability.
CBM	Capacity Benefit Margin.
TRM	Transmission Reliability Margin.
ETC	Existing Transmission Commitments.
ATC	Available Transfer Capability.
ANN	Artificial Neural Network.
GPS	Generalized Pattern Search.
GTNET	Giga-Transceiver Network Communication Card.
SKT	Socket Protocol
GTSYNC	Synchronization Card.
RTDS	Real Time Digital Simulator.
TSO, DSO	Transmission, Distribution system operator.
TN, DN	Transmission, Distribution network.
TS, DS	Transmission system, Distribution system level.
DER	Distributed energy resources.
PV DER	Solar PV based distributed energy.
WIND DER	Wind based distributed energy.
VVC	Volt-VAR control devices.
ADN	Active distribution network.
ADS	Active distribution system.

TNO	Transmission network optimizer.
ITD	Integrated Transmission and Distribution framework
T&D	Transmission and Distribution System
MAS	Multi-Agent System.
EV	Electric Vehicle.
MG	Micro-grid.
RTCA	Real-Time Contingency Analysis.
VVO	Volt-VAR Optimization.
EVSE	Electrical vehicle supply equipment.
\mathcal{A}, α	Agent vector.
\mathcal{A}_i^j	j^{th} component of i^{th} agent vector.
na	Cardinality of agent vector.
na_i	Cardinality of i^{th} agent vector.
<i>Agent2tr, tr2Agent</i>	Subroutine protocols invoked by MAS.
<i>Agent2dn, dn2Agent</i>	
$Pd_t^{pcc,i}$	Total load at i^{th} pcc node at time t .
α_{Pd}^{DN}	agent component containing the equivalent load of <i>ADN</i>
P_{PV}^i, P_w^i	Power output of PV and wind at i^{th} bus.
$P^{inv}, P_{losses}^{inv}$	PV inverter power output and losses.
ADS_{load}	Aggregated load of active distribution system.
$Q^{inv}, \eta_{inv}, S^{max}$	PV inverter reactive power, efficiency and maximum rating of smart inverter.
v, v_{ci}, v_{co}, v_N	Velocity, cut in, cut out, and nominal wind velocity
B_{svc}	Equivalent susceptance of SVC.
PD^{TS}	Load at transmission level.

ADS_{Pd}^{DS}	Agent component containing aggregated load of ADS.
$X_C, X_L, \alpha_f, X_{TCSC}$	Capacitive, inductive reactance, firing angle and equivalent reactance of TCSC.
Pd^{DS}	Net load of active distribution feeder.
τ	The number of active distribution feeders.
SoC	The state of Charge.
ρ	Probability of requesting connection by EV from charging station.
η_{sk}	Skewness factor.
E^{EV}, P^{EV}	EV energy, Power absorbed or injected.
l_{oc}, v_{id}	Location of EV, vehicle identity.
c^r, d^r	Charging/Discharging rate of EV.
t_{start}, t_{stop}	EV charging/discharge start and stop time.
P^{MG}, Q^{MG}	Active and reactive power injected/drawn by MG.
θ_{ij}	Admittance angle of the line connecting buses $i \rightarrow j$.
δ_i, δ_j	Voltage angle of buses i and j .
$Pd_{i,t}^{TN}, Pg_{i,t}^{TN}$	Active power demand and injections of transmission level at i^{th} bus.
$Qd_{i,t}^{TN}, Qg_{i,t}^{TN}$	Reactive power demand and injection of transmission level at i^{th} bus.
$Pd0_{i,t}^{TN}$	Base Case Active power demand in transmission level of i^{th} bus at time t .
$P_{L,t}^i$	Load at i^{th} node in the ADN at time t .
c, C	Set of credible contingencies.
$V_{i,t}^{DN}, V_{i,t}^{TN}$	Voltage at DN and TN levels of i^{th} bus.
$V_{i,t}^{min,DN}, V_{i,t}^{min,TN}$	Minimum voltage at DN and TN levels of i^{th} bus.

$V_{i,t}^{max,DN}, V_{i,t}^{max,TN}$	Maximum voltage at DN and TN levels of i^{th} bus.
$P_{i,j}^{min,TN}, P_{i,j}^{TN}, P_{i,j}^{max,TN}$	Power flowing through line $i \rightarrow j$ and its minimum and maximum values at TN.
q, F	Feeder number and last feeder.
ζ	Acceleration factor.
$G_{q,t}^{DN}, B_{q,t}^{DN}, Y_{q,t}^{DN}$	Conductance, susceptance, and admittance of feeder q in p.u.
$g_{ij,t}, b_{ij,t}$	Conductance and susceptance matrix between nodes i and j of feeder q .
$Q_{i,t}^{cb}, \beta_{i,t}^{cb}$	Capacitor bank (CB) capacity, integer value for capacitor bank unit.
cb	capacitor bank setting.
$\Delta q_{i,t}^{cb}$	VAR value of each capacitor in CB.
$\gamma_{tr,t}$	Off-nominal turn ratio of OLTC and voltage regulator.
$\Delta V_{tr,t}$	Voltage change for tap position.
t, T	Time interval, last time interval.
tap	Transformer tap.
SI, DI	Static and Dynamic information.

PREFACE

The nascent advances in technology and the global emphasis on sustainable development through clean and green power sources are transmuting the conventional analysis, monitoring, and control aspects of the power sector. Traditionally, the power system was mainly comprising of generation utilities, transmission utilities, and distribution utilities vertically integrated with centralized generation and unidirectional power flow. The power flow was primarily directed from Power generating sources to industrial, residential, commercial, or agricultural loads through the transmission network. Later, with the introduction of open access and deregulation, the monopolistic and centralized system transformed into a decentralized and horizontally integrated system. This enabled the independent power producers to inject and sell Power to the grid.

The introduction of deregulation and open access brought a competitive environment among the generation and distribution sector and complicated the task of independent system operators. The enhanced emphasis on distributed generation with high dependence on PV and Wind-based sources under both grid-connected and off-grid modes provided the consumers with the ability to meet their requirements and sell back locally or to the grid. Such consumers are being termed as prosumers.

Under the prevalence of Distributed Energy Resources (PV and Wind) and Virtual Power Plants (Electric Vehicles), there are chances of a reversal of Power from Active Distribution Networks to the transmission and sub-transmission levels. In such circumstances, the conventional notion of segregated analysis of transmission and distribution would not remain viable. The authenticity of the T&D system's segregated analysis could be challenged because the phenomena happening at the transmission level

would now be affected by those occurring at the distribution level and vice versa. Thus, adequate frameworks for analyzing the integrated analysis of T&D systems need to be developed.

The overall power system's exact situational awareness has always been vital for adequate power system operation. Available Transfer Capability (ATC) is an indicator of the remaining transfer capability in the system. The availability of information pertinent to ATC would empower the system operator to take the most techno-economically feasible decision. In this research work, we have promulgated: -

- ATC assessment and enhancement methodology.
- The Pseudo-PMU (PPMU) emulation for quasi-static analysis and offline data generation of power systems has been developed.
- A framework for real-time ATC assessment has been proposed.
- ATC assessment of Integrated Transmission and Distribution.
- ATC assessment of Integrated Transmission and Distribution (ITD) considering Electric Vehicles and Microgrids as an element of Active Distribution System (ADS).
- Energy transaction using the blockchain-based framework and its impact on Aggregated Load Profile and Available Distribution Capability has been discussed.

The first part presents a method for ATC assessment and enhancement. The problem of ATC assessment has been solved by using pattern search optimization. The Flexible AC Transmission System (FACTS) devices can modulate the power flow through the lines and be optimally tuned to enhance the system's ATC. The devices, namely TCSC and SVC, have been considered and modeled, and the method for determining optimal operational strategies for maximizing the ATC of the system has been inked.

To develop the real-time ATC assessment technique based on Artificial Neural Networks (ANN), extensive training and testing data sets would be required. The synchrophasor measurement devices are capable of providing time-synchronized measurements across the grid. Such information could be considered as a first information report of events happening in the system. The measurement information could be directly utilized for various monitoring, control, and protection applications. Thus, for offline simulation gathering, PMU data was an issue; a pseudo-PMU emulation method has been developed and presented in the second part to tackle this issue.

In the third part, an ANN-based ATC estimator has been developed. The proposed method employs the radial basis neural network for estimating the ATC. The methodology involves feature extraction and linear state estimation. The developed method has also been tested on a real-time testbed using a Real-Time Digital Simulator (RTDS). The OPENECA software has been used to acquire the PMU measurement from the 'GTNET PMU' available in RTDS to MATLAB script, where the developed ATC estimator is employed to estimate the ATC.

Understanding the effect of large-scale deployment of distributed energy resources requires the development of a framework for integrated analysis of T&D analysis. Therefore, a multi-agent-based framework for integrated analysis of transmission and distribution systems has been propounded in the fourth section. The developed technique has been to assess the effect of ADN on the ATC of the system. The ADN employs CVR as a Volt-VAR optimization tool, and the impact of the same has also been assessed.

Advancing the research further, in section fifth, the effect of the presence of Electric Vehicles (EVs) capable of acting as Virtual Power Plants (VPP's) and microgrids capable of withdrawing/injecting Power to the ADN have been considered. Two indices, namely

ATCVR and ATCE factor, have been proposed as measures to assess the overall impact of considering the ADN on the ATC of the System.

The advent of the decentralized ledger and computing technology with cryptographic security paves the way to a new market structure where the various market participants could bid and actively participate in the bid settlement process. The sixth part of the work is dedicated to assessing the application of blockchain-based energy trading in IoT (Internet of Things) rich ADS and its probable impact on ADC as well as aggregated load profile of the ADS.