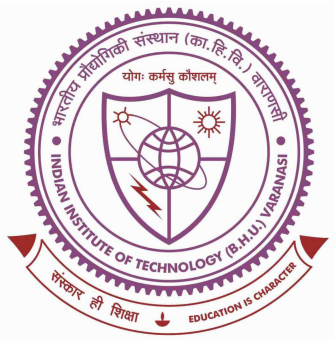
Formulation and detection of false data injection attack in modern smart grid



Thesis submitted in partial fulfillment
for the award of degree

Doctor of Philosophy

by

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2022

Dedicated

To

My father, mother, brother, family and friends

CERTIFICATE

It is certified that the work contained in the thesis titled **Formulation and detection of false data injection attack in modern smart grid** by **Debottam Mukherjee** has been carried out under our supervision and that this work has not been submitted elsewhere for a degree. It is further certified that the student has fulfilled all the requirements of Comprehensive Examination, Candidacy and SOTA for the award of Ph.D. Degree.

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DECLARATION

I, **Debottam Mukherjee**, certify that the work embodied in this thesis is my own bonafide work and carried out by me under the supervision of **Dr. Sandip Ghosh** and **Prof. Rakesh Kumar Mishra** from July-2017 to November-2022, at the Department of Electrical Engineering, Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports dissertations, theses, etc., or available at websites and have not included them in this thesis and have not cited as my own work.

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It is certified that the above statement made by the student is correct to the best of my/our knowledge.

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Though, only my name appears on the cover of this dissertation, so many great people have contributed to its production. I owe my gratitude to all those people who have made this thesis possible and because of whom my post graduate experience has been one that I will cherish forever.

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Debottam Mukherjee

Date: 21.09.2023

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Nomenclature

List of Abbreviations

AMI	Advanced metering infrastructure
ARIMA	Autoregressive integrated moving average
BDD	Bad data detector
Bi-LSTM	Bidirectional long short term memory
CNN	Convolution neural network
D-FACTS	Distributed flexible ac transmission system
DDOS	Distributed denial of service
DNN	Deep neural network
DT	Decision Tree
EMS	Energy management system
FDIA	False data injection attack
FSVD	Full order singular value decomposition
GPS	Global positioning system
IIOT	Industrial internet of things
LSTM	Long-short term memory
MAE	Mean absolute error

MITM	Man in the middle
MLP	Multilayered perceptron
MSE	Mean squared error
NASV	Number of attacked state variables
PDC	Phasor data concentrator
PMU	Phasor measurement unit
RMSE	Root mean squared error
ROC	Reciever operating characteristics
RSVD	Reduced order singular value decomposition
RTU	Remote terminal unit
SCADA	Supervisory control and data acquisition
SVD	Singular value decomposition
SVM	Support vector machine
WAMS	Wide area monitoring system

List of Variables and Parameters

$\hat{x} \in \mathcal{R}^n$	Estimated operating states
$a \in \mathcal{R}^m$	Attack vector
$c \in \mathcal{R}^m$	Error vector for the estimation model
$H \in \mathcal{R}^{m \times n}$	Topology matrix of the grid
$h(.) \in \mathcal{R}^m$	Nonlinear function relating the set of available measurements with the operating states of the grid
r	Measurement residual

$W \in \mathcal{R}^{m \times m}$	Weight matrix of the respective meters
$x \in \mathcal{R}^{n}$	Set of operating states
$z \in \mathcal{R}^{m}$	Set of acquired measurements at the control center