

# REVIEW ON SMART GRID SECURITY ANALYSIS USING PMU STATE ESTIMATION

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**Abstract**—The electricity demands are increased rapidly with low power losses and low energy costs. To minimize the power loss and achieve load demand with that developing new energy sources based on Renewable energy sources are necessary to think. The controlling and achievement of about goals is difficult in the normal power grid, so smart grid development is increased in the recent few years. While the biggest issues related to SG is security. The vulnerability of SG against cyber-attacks is discussed in this paper. The Bad data injection, False Data injection, and cyber-attacks are the most focusing challenges reviewed in this paper. The PMU state estimation is one promising solution for SG security. The Review on PMU State estimation and its role for SG Security is discussed in this paper.

**Keywords**—SG, PMU, BDD, State Estimation (SE), FDI, etc.

## I. INTRODUCTION

In electrical grid network the only key objective is to maintain the balance between load demand and power generation. Smart grid provides two way communication between power supplier and consumer through digital control. SG infrastructures includes Information communication control, Automation, Computers and information control. The smart grid provides control over power supply as per the demand variation quickly through new technology and digital control. The smart grid concept provides new technology development, dependability, availableness, and new opportunities for electricity market. The key benefits of development of SG over power grid are explained below.

The advantages related to the Smart Grid include:-

- Reliable and low cost power transmission
- Fast response and quick restoration during abnormal conditions
- New technology development helps in reduction of operation and management costing

- The peak demand of electricity is also reduced which helps for low electricity rates to consumer
- Power demand achieved using integration of renewable energy sources
- Data security and management is done easily
- Load balance achieved between demand and generation

The outline of the paper is as follows. Section II discuss the literature review for the problem identification and our motivations on developing the methods for SG security. The challenges and key research objectives are also explained in this section. In Section III, the analytic vulnerability assessment with different control methods are discussed. The benefits and drawbacks of different control methods are explained w.r.t to Phasor Measurement Unit (PMU) state estimation. The co-simulation platform for SG security is explained in Section IV, including how the power system and communication network are modeled. Section V shows the Matlab simulation and results for IEEE 14-bus system SG security with the help of PMU state estimation. We also provide a discussion on simulation results. The conclusion remarks are in Section VI.

## II. CHALLENGES AND RESEARCH OBJECTIVES FOR S.G SECURITY

**Literature Review:-**

*Anurag Srivastava, Thomas Morris, Timothy Ernster, , Ceeman Vellaithurai, , Shengyi Pan, and Uttam Adhikari [1]* shows the cyber-attacks modelling using Vulnerability analysis of Data and information control in grid network. The proposed Vulnerability analysis of electric grid has been analyzed with graph theory based approach.

In this control topology the grid network utilizing the different concepts like feasibility, communication control, detection of threat which is implemented and verified for IEEE 14 bus system by the authors in this paper [1].

**James Ranjith Kumar R. and Biplab Sikdar [2]** presents simplified non calculative false/bad data detection using AC State Estimation technique. The proposed AC State estimation system calculates the data of Voltage magnitudes and Node power injection through SCADA. In this paper the authors tested proposed control methods for IEEE 118 bus system in which FDI injected around 1% to 10 % magnitude variation. The controlling of Power flow and voltage magnitude is done in proposed system [2].

**Kaikai Pan, Andr'e Teixeira, Claudio David L'opez and Peter Palensky [3]** Provides implementation of PMU State estimation technique with optimal power flow control for optimization point of view. The Grid Network parameters are measured and compared with the Data measured during the Bad data injection and PMU SE gives the variation and error signal from iteration calculation proposed in this paper [3].

**Jingyao Fan, Youssef Khazbak, Jue Tiany, Ting Liu and Guohong Cao [4]** shows that in today's grid network the data measurement and control is done through SCADA network. In S.G network when attacker do FDI on smart meters which creates problems on meters technology. The existing technology will meet consider the costing of smart metering in S.G. The main objective of the authors in this paper is how to done the selection of most critical meters to protect them against cyber-attack. The algorithm developed by the authors is based on heuristic based solutions. In the proposed controlling in this paper will provides two main concepts:-

1. Identification of the meter which will be targeted by the attacker in FDI as cyber-attacks.
2. Identify the damage which will be caused by the attack on the meter.

**HADIS KARIMIPOUR, AND VENKATA DINAVAHU [5]** this paper represents the overview of smart meter security against cyber-attacks and FDI. The vulnerability analysis will plays an important role for smart grid. In this paper the authors shows that the solution for FDI and cyber-attack threat is state estimation. The authors represents the markov chain theory and Euclidean distance metric for state estimation controlling.

In this paper the proposed robust state estimation used trusted historical data of bus network and calculate the bad data as FDI attack values in S.G.

The proposed robust state estimation algorithm is built with the help of fine gained parallel programming technique.

#### Challenges:-

Smart grid infrastructure is facing number of threats for security concern including cyber-attacks, FDI, terrorism, natural disasters, etc. The failure of SG due to any of above threats creates multiple issues in power grid like failure of equipment, power cut-off, blackout, information network disturbance or failures, cascaded tripping etc.

Different Security threats and challenges of smart grid have been presented in Pan, and Uttam Adhikari [1], James Ranjith Kumar R. and Biplab Sikdar [2], Abdulrahman Okino Otuoze, Mohd Wazir Mustafaa, Raja Masood Larik [5]. These threats and challenges have focused researcher towards study and research about privacy and security of smart grid by different techniques.

SG security challenges considered in terms of authentication, authorization, and privacy of technologies depending on security levels of SG. From the technical point of view, threat of security is concerned with fault or breakdown of generation, transmission, distribution, and substation; due to natural of non-natural cause such as failure of equipment, commanding operation due to false data injection.

Now a days time has come where people are very much concern with the security concept of grid network because in recent scenario and in nearby future development of smart grid is increased. Normal and healthy operation of smart grid is much concern topic against uncertain problems and cyber-attack on grid network. For security concern there is a need of approach in which we can identify the cyber-attacks that is seeking to damage grid network and provide controlling to prevent collapse & problems occurs due to cyber-attacks [4].

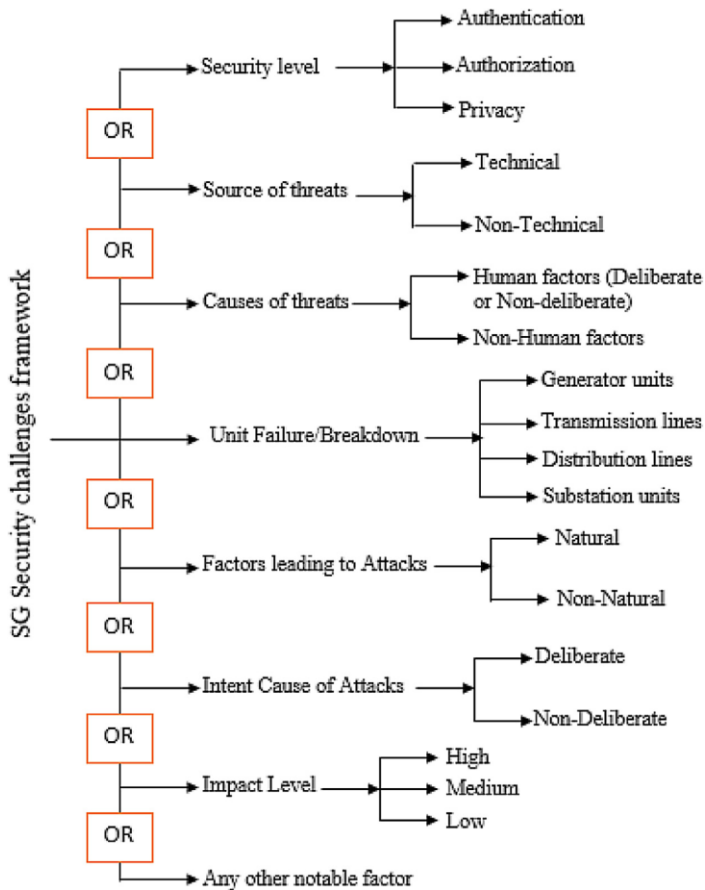


Fig. 1. Framework for identifying smart grid security threats and challenges [5]

**Research Objectives: -**

As discussed earlier, reliable and efficient electricity supply to consumer depends on interconnectivity and interdependency of the SG infrastructures with data control through SCADA. Therefore, well-articulated security objectives are mainly considered for ensuring an efficient and reliable operation of smart grid. These objectives include all possible expansion & improvement plans for future grids development. Here in this paper main objectives are: -

- Detection of False Data Injection (FDI) in SG infrastructures and provides security through PMU State Estimation.
- Integration of renewable energy unit for electricity supply as DG unit in SG as DG unit is also of utmost priority since it can be used for increasing the security requirements between electricity generation and demands.

Implementing the Security for smart grid against FDI provides efficient and reliable operation of smart grid. The data security and authentication objective is achieved using Security of SG.

**Smart grid Architecture: -**

The SG has been the best solution in replacement of conventional electrical grid network to minimize the power loss and improve system parameters like effectiveness, security, privacy, reliability, stability, efficiency and to achieve the balancing for increasing load demand [7]. The main features of SG include safe and secure operation, self-healing capability, improved power quality, fast response, energy management, Distributed Generation (D.G) unit integration, etc. The fig.2 shown below shows the architecture of smart grid with power flow management including different types of networks WAN (Wide Area Network), HAN (Home Area Network) and NAN (Neighborhood Area Network). Firstly the HAN type network manages the consumer power demands and smart devices (including smart meters, smart sensors, etc.) operations [7]. HAN is first layer network while NAN which is known as Filed Area Network (FAN) is considered as the second layer SG and SMI belongs to multiple HAN networks. NAN network helps for two way communication between the distribution system and field electrical components like meters, sensors and measurement devices. In that system, the data from multiple HAN networks are combined for service and metering information and it will transmit to the data collector with NAN to WAN network configuration. The third and last layer is WAN which serves as a backbone of communication for the network to gateways [7].

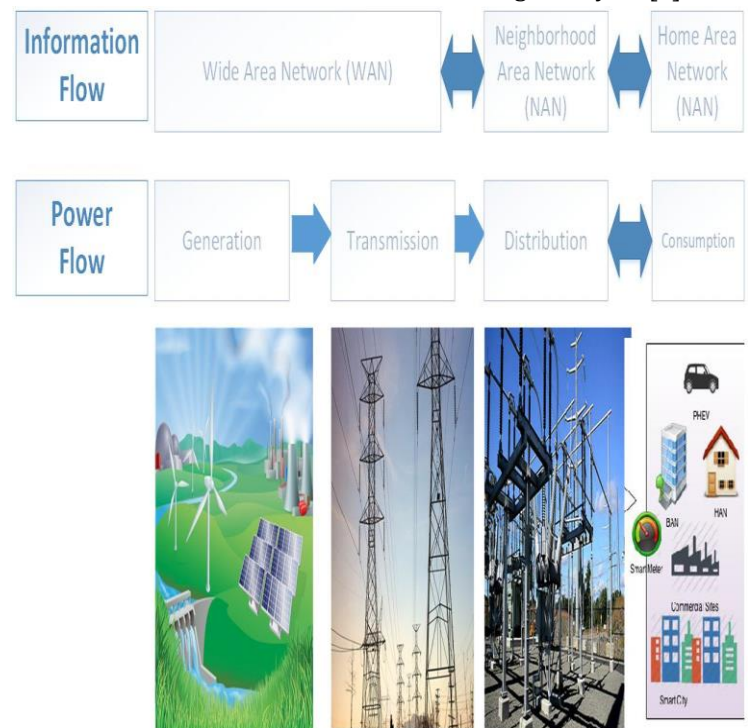


Fig.2 Architecture of Smart grid (SG) with power flow indication [7]

### III. PROPOSED WORK AND VULNERABILITY ASSEMENT

In this paper we will develop IEEE-14 bus system network using MATLAB-Simulink and measure load flow analysis including load demand, line data, generation data, line outage factors, etc. After Cyber-attack, the line data becomes unbalanced and line outage problem occurred. To mitigate this, we will implement the PMU state estimation that provides an estimate of Smart grid Network in Data Attack Condition. The proposed State Estimation uses measurements collected by the Remote Terminals of Substations in Grid and provides data to SCADA base DCS Control system. The estimated state information will be processed by optimal power flow and Contingency analysis to calculate the necessary steps for safety and reliability of system. If the fault condition is not removed or it affects other bus system than proposed approach will remove that faulty part using C.B operations in the Smart grid and provides balancing and security in the system.

Fig.3- Closed Loop control system for Smart grid Security [3]

The proposed controlling of PMU State Estimation as shown in Fig.1 the data attackers can attack from various points like A1- Remote terminal unit, A2-Communication Network, A3- SCADA master. The Data measurements under such type of attacks are presented as following steps:-

1. Bad Data Injection: - In this type the attacker tries to inject false or bad data in the grid network, state estimation provides data changes from  $K$  to  $K+a$ , where  $K$  is Bad data Attack vector.
2. Vulnerability Analysis:- The Vulnerability Analysis calculate how many measurements need to be manipulated by the attacker to keep Stealth against Bad Data Detection (BDD).
3. PMU State Estimation: - In the PMU State Estimation Method the Node power injections and Line power flows are calculated from DCS system and Voltage Magnitudes and Angles from Phasor measurement Unit (PMU) for detection of bad data attacks.
4. Iteration Calculation of SE: - In Calculation of SE the iteration steps are repeated until the values of State Variables converge to specified tolerance limits. In this grid network by assuming voltage magnitudes are near to specified limits and difference of voltage angles in line are very small then the equation may be linear and can be solved with better accuracy. If that condition is not

satisfied then it indicates that bad data is present in the system [3].

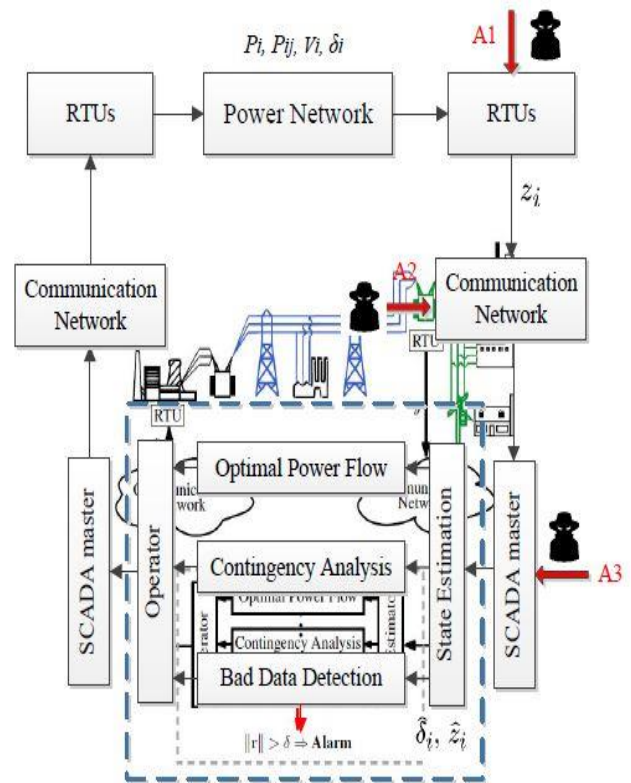


Fig.3- Energy Management System [1]

#### Classification of Cyber-attacks:-

1. **Component Wise:** - Field Components like RTU are attacked through remote access.
2. **Protocol Wise:** - Using the communication protocols available in the public domain, an intruder can reverse engineer data acquisition protocols and exploit them.
3. **Topology Wise:** - Network Topology Vulnerability is exploited. Example: - Attacks on SG Portion/Parts.

### IV. STATE ESTIMATION AND BAD DATA DETECTION

As shown in fig.2 the Remote Terminal Units (RTU) transmit the data of node power injections, line power flows, bus and line voltage magnitudes to Supervisory Control and Data Acquisition (SCADA) controlled Digital Control System (DCS) centre for Energy Management System (EMS). The different type of network topologies are used for this. In power grid PMU will measure the voltage and current phase angles for state estimation calculations. The measured signal from PMU is transmitted through a filter and amplifier for signal amplification. The measured quantities are used for the EMS system to identify in which state power system is operated.

The use of power balance equation is not suitable because of its nonlinearity in nature, which focus for the use of Gauss-Newton method for state estimation which is known as A.C state estimation.

For example we consider  $z$  to be the  $m$  dimensional vector for all the calculations in SE and function  $f(x)$  to be considered as nonlinear function used for variable  $x$  measurement in PMU during state estimating. This  $x$  will representing the voltage magnitudes and angles of node, which dimensional size  $n$  is assumed to be less than the  $m$  measurements in SE. From this we can say that making system an over determined the necessary condition is  $n < m$ .

The measured quantities have noise signal in the measurements we used following equation for state variables calculation:-

$$z = f(x) + e \tag{1}$$

Where,

$e$ = noise signal present in measured quantity

This calculations and measurements is nothing but the set of power balance equations which is nonlinear in nature. Due to which the state estimation calculations steps are usually iterative. For example at the  $i^{th}$  iteration, the state correction vector is written as below

$$\Delta x^i = (H^T(x^i)R^{-1}H(x^i)) \setminus H^T(x^i)R^{-1} (z - f(x^i)) \tag{2}$$

Where,

$H(X^i)$  = Jacobian matrix for the function  $f(X^i)$  and

$R$ =measurement covariance matrix.

Using the state correction vector, the values of the state variables for the next iteration can be updated as

$$X^{i+1} = X^i + \Delta X^i \tag{3}$$

This calculation method of iteration will be repeated up to the state variables values converge to the reasonable tolerance limit. For linearization in the power model calculations we are assumed that the measured voltage magnitudes are closer to the rated values and difference of voltage angles in a line are extremely small. This technique is simple for iterative solution and it is known as DC state estimation.

**Vulnerabilities:-**

For SG, a big challenge is to provide enhancements and improved capabilities compared to the normal power grid. These vulnerabilities will allow the network access and it will loss the data security and integrity of transmitted data to the service provider. The following vulnerabilities are the most serious in SG:

**1) Customer security:** Smart meters collect information and data of usage, and transfer it to the consumer, utility companies and service provider.

This data includes consumers' personal information and consumers' activities such as devices being used when the home is vacant.

**2) Greater number of intelligent devices:** The SG has several intelligent devices that are used to manage load demand and generation. These intelligent devices may act as attack entry points into the network. Moreover, the massiveness of the SG network makes network monitoring and management extremely difficult.

**3) Physical security:** Unlike the traditional power system, SG network includes many components and most of them are out of the utility's premises. This fact increases the number of insecure physical locations and makes them vulnerable to physical access.

**4) The lifetime of power systems:** Since power systems coexist with the relatively short-lived IT Systems, it is inevitable that outdated Equipments are still in service. This equipment might act as weak security points and might be incompatible with the current power system devices.

**5) Implicit trust between traditional power devices:** Device-to-device communication in control systems is vulnerable to data spoofing where the state of one device affects the actions of others. For instance, a device sending a false state makes other devices behave in an unwanted way.

**6) Different Team's backgrounds:** Inefficient and unorganized communication between teams might Cause a lot of bad decisions leading to much vulnerability.

**7) Using Internet Protocol (IP) and commercial off the-shelf hardware and software:** Using IP standards, SG offers a big advantage as it provides compatibility between the various components. However, devices using IP are inherently vulnerable to many IP-based network attacks such as IP spoofing, Tear Drop, Denial of Service, and others.

**8) More stakeholders:** Having many stakeholders might give rise to a very dangerous kind of attack: insider attacks.

**Phasor Measurement Unit (PMU) For SE**

Development of Phasor Measurement Units (PMUs) was began in the mid-1980s. At the network buses, to synchronize measurements of positive sequence voltage phasor, and positive sequence current phasor in the line connected to those buses, PMUs use GPS signals. This process of synchronization has the accuracy of better than one microsecond.

The available result from the set of measurements renders a real time snapshot of the state of the power system. Positive sequence voltages at all network buses represent the state vector of a power system, so for the ease of the process, Phasor measurements can solve the state-estimation problem, solely. With these measurements, one is led to a process that calculates the system state, instead of reckoning it using measurements that are nonlinear functions of that state. But the main drawback of using PMUs is that they are very expensive. As additional measurements with the traditional measurements, PMUs can be used. In spite of the fact that, a phasor-based state vector measurement system is an authentic technique to traditional state estimators, it is recognized that in many cases, one is not efficient to come up with adequate amount of numbers to attain this goal. Results proved that the accuracy of the state estimate is much improved, when phasor measurements are included to the other measurements in the ample amount of numbers. And because of that, different methods are adopted to include the phasor measurements into the traditional measurement.

A **phasor measurement unit (PMU)** is a device used to estimate the magnitude and phase angle of an electrical phasor quantity (such as voltage or current) in the electricity grid using a common time source for synchronization. Time synchronization is usually provided by GPS and allows synchronized real-time measurements of multiple remote points on the grid. PMUs are capable of capturing samples from a waveform in quick succession and reconstructing the phasor quantity, made up of an angle measurement and a magnitude measurement. The resulting measurement is known as a synchro phasor. These time synchronized measurements are important because if the grid's supply and demand are not perfectly matched, frequency imbalances can cause stress on the grid, which is a potential cause for power outages.

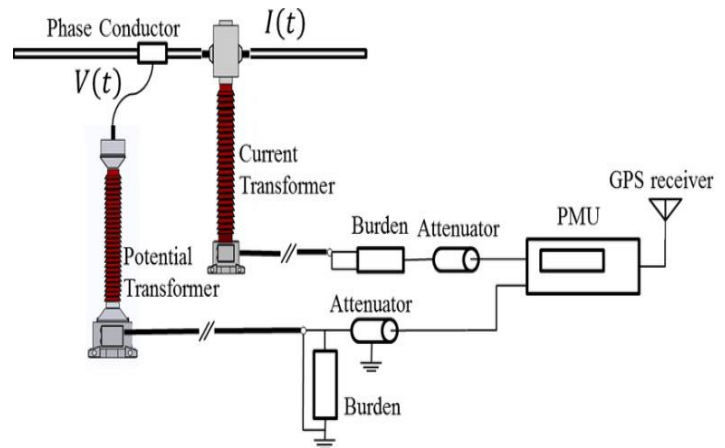


Fig 4- PMU Installation and connection diagram

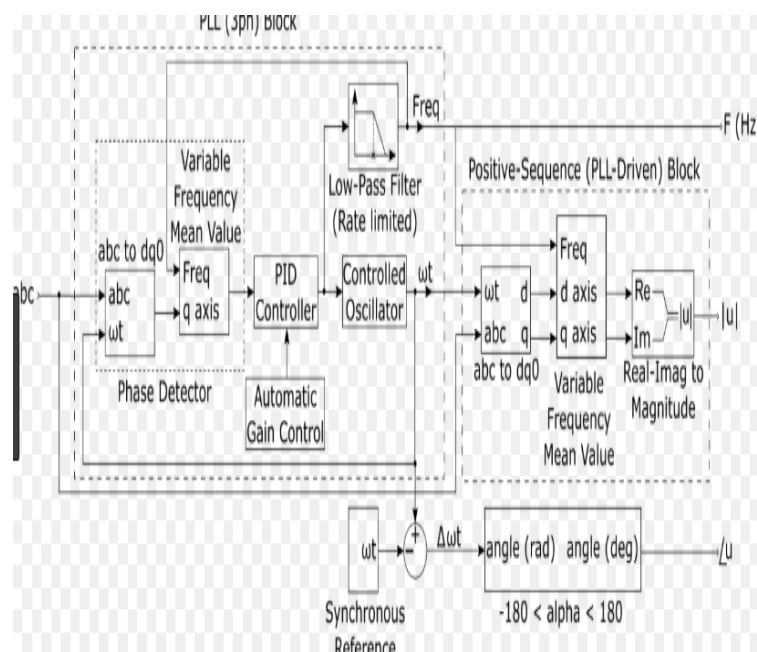


Fig 5 Implements a phasor measurement

**V. CONCLUSION**

As discussed in this paper we can say that the cyber-attack in SG has several effects on grid parameters magnitudes variation. The review on SG architecture, SG security and vulnerability analysis are discussed. The role of state estimation for SG security also represented, for validation the simulation has been carried out for IEEE 14-bus system. The simulation results shows the impact of cyber-attacks on generation profiles and active power flow of bus-1 and bus-2. The successful implementation of PMU is also implemented with discussion and improvement in active power flow is shown in simulation results.

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