

**Economic Integration of Smart Grid Using Renewable Energy Sources.**

Submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology

**In**

**Electrical Engineering**

**By**

**TANMOY PAUL**

**UNIVERSITY ROLL NO: 35501618001**

**REGISTRATION NO: 183550110035 OF 2018-2022**

**Under the guidance of**

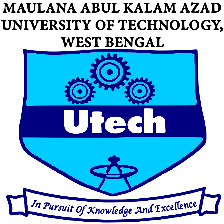
**Dr. Sandip Chanda**



**Electrical Engineering Department**

**GHANI KHAN CHOUDHURY INSTITUTE OF ENGINEERING AND TECHNOLOGY**

**June 2022**





**GHANI KHAN CHOUDHURY INSTITUTE OF ENGINEERING AND TECHNOLOGY**

**Malda**

**FOREWARD**

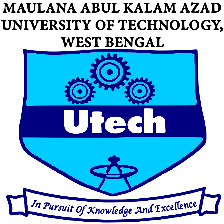
We forward the thesis entitled “ECONOMIC INTEGRATION OF SMART GRID USING RENEWABLE ENERGY SOURCES” submitted by MR. TANMOY PAUL (UNIVERSITY ROLL NO: 35501618001, REGISTRATION NO: 183550110035 OF 2018-2022) as a bona fide record of the project work carried out by him under the guidance and supervision of the undersigned in a partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Electrical Engineering from the institute under MAULANA ABUL KALAM AZAD UNIVERSITY OF TECHNOLOGY,WEST BENGAL.

**Dr. Sandip Chanda**

( Professor and Head of the Department) Electrical Engineering,

Ghani Khan Choudhury Institute of Engineering and Technology

Pincode- 732141





**GHANI KHAN CHOUDHURY INSTITUTE OF ENGINEERING AND TECHNOLOGY**

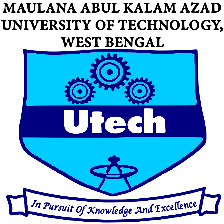
**Malda**

**CERTIFICATE OF APPROVAL**

We forward the thesis entitled “ECONOMIC INTEGRATION OF SMART GRID USING RENEWABLE ENERGY SOURCES” submitted by MR. TANMOY PAUL (UNIVERSITY ROLL NO: 35501618001, REGISTRATION NO: 183550110035 OF 2018-2022) as a bona fide record of the project work carried out by him under the guidance and supervision of Dr. Sandip Chanda, in a partial fulfillment of the requirements for the award of the degree of Master of Technology in Electrical Engineering from the institute under MAULANA ABUL KALAM AZAD UNIVERSITY OF TECHNOLOGY,WEST BENGAL.

**BOARD OF EXAMINERS**







**GHANI KHAN CHOUDHURY INSTITUTE OF ENGINEERING AND TECHNOLOGY**

**Malda**

**DECLARATION**

I declare that this written submission represents my ideas in my own words and others ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

(Tanmoy Paul)



(University roll no.)



(Class roll no.)



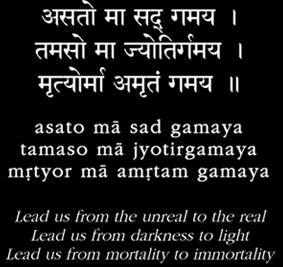
To

*My Family*

**Acknowledgement**

My deepest gratitude goes to Dr. Sandip Chanda of the department of Electrical Engineering of the  
Institution for his invaluable direction and supervision work, his wise advice, his patience, and for  
allowing me the opportunity to develop this work. From very first day of my project work, he has been  
kind and firm in showing me the right direction, being there for me in all my queries and quandary, and  
destining me to my objectives. Sir, without your constant encouragement and tremendous support I  
would have been “lost”. I highly appreciate the co-operation of my fellow researchers, all laboratory and non-teaching staff of this Department, for helping me directly or indirectly in framing this research in its form. Though it is beyond the scope of any acknowledgement what I have received from my family members in form of inspiration and encouragement, yet I make a humble effort to express my profound gratitude towards them.

**June 2022 Tanmoy Paul**



**Table of contents**

**List of abbreviation ix**

**List of Figures xiii**

**List of Tables xiv**

**1 Introduction 1.1**

* 1. Literature review 1.6
  2. Motivation behind the work 1.12
  3. Thesis organization 1.12

**2 Distance relay and three zone protection scheme 2.1**

2.1 Operational characteristics of Impedance relay 2.1

2.2 Operational characteristics of Mho relay 2.4

2.3 Three zone protection 2.5

**3 Present distance protection problem 3.1**

3.1 Matlab simulink modeling 3.2

3.1.1. Three-phase source 3.2

3.1.2 Voltage measurement 3.3

3.1.3 Current measurement 3.4

3.1.4 Three-phase fault 3.5

3.1.5 Three-phase series RLC load 3.7

3.1.6. The developed three zone protection scheme model 3.8

* + 1. Average impedance 3.9
    2. RMS 3.10

3.1.9. Distance mean value 3.12

3.1.10. Average voltage 3.13

3.1.11. Average current 3.14

3.1.12. Instantaneous 3.15

3.1.13. Backup 1 3.16

3.1.14. Backup2 3.17

**4 Calibration of the simulink model with standard numerical relay 4.1**

4.1 Description of the standard numerical relay 4.1

4.2 Determination of different relay setting with reference to standard numerical

relay 4.16

**5 Development of 3 zone protection 5.1**

5.1 Operational characteristics of the simulated relay model 5.1

5.2 Minimization of the operational logic 5.3

5.3 Operation of the simulink in matlab 5.8

**6 Development three zone protection excluding undesired**

**overload trip 6.1**

6.1 Simulink model at undesired overload trip 6.1

6.2 Discrepancy between with outage and without outage conditions 6.5

**7 Summary, conclusion, contributions and future research 7.1**

7.1Thesis Summary 7.2

7.2 Conclusions 7.2

7.3 Major Contributions of the Present Thesis 7.3

7.4 Scope of Future Work 7.3

**8.1 Case studies 8.1**

**Appendix**

**A** **Introduction to MATLAB A.1**

**A.1. Historical background A2**

**A.2. Interfacing with other languages A2**

**A.3. MATLAB simulation A3**

**A.4.Modeling, Simulation, and Analysis with Simulink A3**

**A.5..Interaction with MATLAB Environment A4**

**A.6.Basic simulation window A5**

**Bibliography**

**List of abbreviation**

**List of Figures**

**List of Tables**

**Chapter 1**

INTRODUCTION

Smart Grid is a concept and vision that captures a range of advanced information, sensing, communications, control, and energy technologies. Taken together, these result in an electric power system that can intelligently integrate the actions of all connected users—from power generators to electricity consumers to those that both produce and consume electricity (“prosumers”)—to efficiently deliver sustainable, economic, and secure electricity supplies. (Source: Definition adapted from the European Technology Platform Smart Grid [ETPSG]).

Researchers have been working around the world to examine and develop the nature of variable Renewable Energy grid integration challenges that have arisen. The major challenges faced during integration of variable RE grid are:

1. Technical Challenges: Ensuring power system reliability as uncertainty and variability increase.
2. Economic, Policy, and Regulatory Challenges: Effectively managing the cost of RE integration and the grid investments that support it, designing policies to harness maximum value from RE, and ensuring that appropriate incentives are in place to encourage appropriate grid investments.

Technical Challenges Two dominant technical challenges can be identified with a higher penetration of RE generation:

1) managing variability and uncertainty during the continuous balancing of the system, and

2) balancing supply and demand during generation scarcity and surplus situations.

**Managing variability and uncertainty during the continuous balancing of the system**

Variable RE sources are both more uncertain and more variable than conventional generators. Wind farms provide a useful illustration of uncertainty: while the farm may reliably produce power for 40% of the hours in a year, it is not easy to predict far in advance when generation will occur.

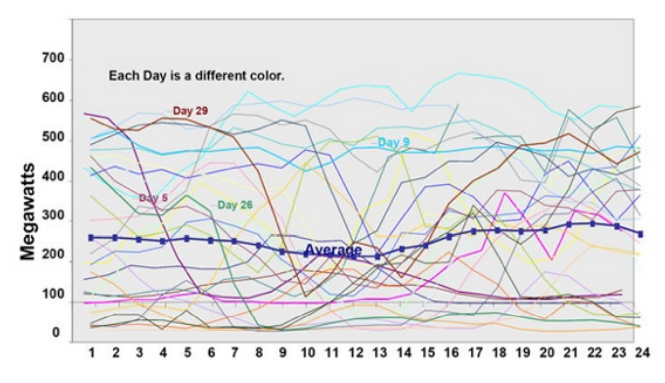


Figure (1.a) Tehachapi wind farm output, 30 successive days (Source: California ISO 2007)

Figure (1.a) illustrates hourly output from a single wind farm on 30 successive days. A rooftop solar installation provides a useful illustration of variability: transient events such as cloud passage can reduce output quite rapidly (see Figure 1.b).

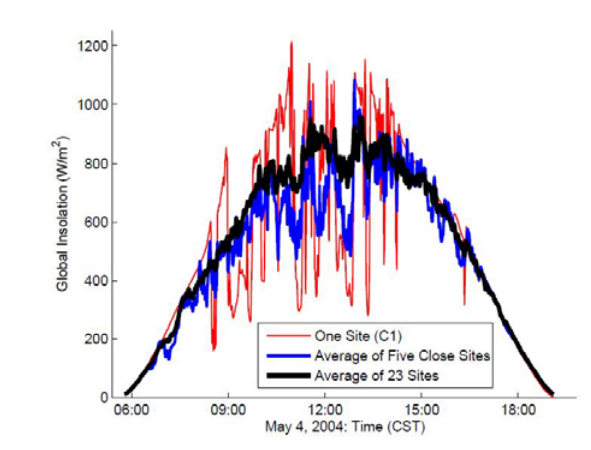


Figure ( 1.b). Example of 1-min global insolation on a partly cloudy day from one site, the average of five close sites, and the average of 23 sites (Source: Mills and Wiser 2010)

Figure (1.b) also illustrates how spreading solar photovoltaics (PV) over a larger geographic area tends to reduce aggregate variability. Generally, solar PV output is more variable than wind (changing faster on a minute-to-minute basis), but it is less uncertain. With both wind and solar power, the ability of system and generation operators to predict generation levels is improving (Bullis 2014).

**Balancing supply and demand during generation scarcity and surplus situations**

Related to but distinct from the previous challenge is system operators’ need to balance supply and demand in situations of high RE production and low demand or low RE production and high demand. Supply of wind and solar may not coincide closely with demand, introducing challenges at the bulk power system level and—if there is significant distributed PV generation—at the local distribution system level. An illustration of the distribution system. challenge is ‘reverse power flow’ that can occur during the middle of the day from areas with large amounts of distributed PV. When most people are out of their homes at work, residential electricity demand is low, so more of the generated electricity feeds back up through the transformer to the medium-voltage network. Distribution systems have not traditionally needed to anticipate this situation because most generation has come from large-scale systems located on the transmission grid, with power flowing predictably one way down to lower voltage systems.

Nighttime wind provides an illustration of the supply-demand challenge on the bulk power system. When nighttime demand is very low and wind is strong (for example on a windy springtime night), there may be insufficient demand to utilize all of the wind power, and conventional generators may not be able or willing to reduce their generation further to make space for the wind power. In this case, insufficient power system flexibility could result in ‘curtailed’ wind power.

Challenges related to high peak load during periods of low variable RE production are less technically demanding and are primarily economic challenges related to market solutions chosen to remunerate reserve capacity or demand response activities.

***Smart grid solutions emerging to manage continuous balancing of the system include:***

*• Better forecasting. Widespread instrumentation and advanced computer models allow system operators to better predict and manage RE variability and uncertainty.*

*• Smart inverters. Inverters and other power electronics can provide control to system operators, as well as to automatically provide some level of grid support.*

*• Demand response. Smart meters, coupled with intelligent appliances and even industrial-scale loads, can allow demand-side contributions to balancing.*

*• Integrated storage. Storage can help to smooth short-term variations in RE output, as well as to manage mismatches in supply and demand.*

*• Real-time system awareness and management. Instrumentation and control equipment across transmission and distributions networks allows system operators to have real-time awareness of system conditions, and increasingly, the ability to actively manage grid behavior.*

**Economic, Policy, and Regulatory Challenges**

In addition to technical challenges, institutional challenges also arise with increasing shares of variable RE. Broadly these relate to the unique economics of variable RE, which give rise to various policy and regulatory issues. Two specific challenges are identified here: capitalintensive grid upgrades, and uncertain project costs and cash flows.

**Capital-intensive grid upgrades**

Grid upgrades may be required to accommodate wind and solar power. For example, to the extent high quality wind and solar resources are located far from demand centers, new transmission lines or upgrades to existing lines may be required. At the distribution level, rooftop PV may accelerate the fatigue of distribution components, such as low-voltage transformers, moving forward the need for grid upgrades. Minimizing the cost of upgrades, while ensuring system reliability, translates to greater value from RE investments.

**Uncertain RE project costs and cash flows**

Smart grid solutions are emerging to two specific issues that historically have negatively impacted RE project economics: grid upgrade costs allocated to RE project developers, and energy curtailment when full RE production cannot be readily integrated into the power system. Both issues may cause cash flows of the project to diverge further from expectation. To the extent upgrades become costly or curtailments increase, the investment landscape for variable RE becomes more uncertain and can slow overall deployment. In cases where policy measures and subsidies insulate project investors from these risks—for example to further enhance the investment environment for RE—costs and risks may be socialized. Smart grid investments can also play an important role in reducing those costs and risks. Cost-effective methods of reducing curtailment and minimizing new transmission or grid upgrades can therefore capture more value from RE sources, improve the viability of individual RE projects, and maximize value to the system, enhancing the overall investment climate.

***Smart grid solutions emerging to address the economic, policy, and regulatory challenges of variable RE include:***

*• Dynamic line rating. Real-time information about transmission line capacity can allow grid operators to extract more value from existing lines, reducing the need for costly upgrades.*

*• Demand response. Enabled by smart meters and intelligent loads, customer demand response solutions can help absorb excess RE generation, reducing the need for distribution upgrades.*

*• Smart inverters and other advanced power controls. Smart inverters and other power controls can reduce the need for significant grid transmission and distribution upgrades, thus reducing costs that may otherwise be levied on RE projects or socialized.*

*• Grid-scale storage. Large-scale storage of various types can help to reduce the need for additional transmission capacity.*

*• Behind-the-meter storage. Customer storage solutions can help absorb excess PV generation, reducing the need for distribution upgrades.*

*• Advanced energy management systems. Advanced energy management systems that provide real-time, high-resolution visibility and control of power systems, can allow grid operators to defer more costly capital expenditures.*

*• Better forecasting. System-level forecasting can help system operators operate their grids more flexibly, allowing more production to be accepted.*

**1.1 Literature review**

This paper proposes an optimization model to maximize social welfare by standardizing the operating conditions with an overall improvement of dynamic stability of power markets endowed with Smart Grid communication technology. For optimum utilization of smart metering facility, the model effectively involves resources like demand response, generation surplus and an efficient methodology to optimize the Market Clearing Price (MCP) as well as profit of the market participants by effective categorization. The power market dynamic price equilibrium has been estimated by forming Jacobian of the sensitivity matrix to regulate the state variables for the standardization of the quality of solution. A novel load curtailment strategy has also been proposed to amalgam stability restoring shedding with profit retentive load cut. The model has been tested in IEEE 30 bus system and IEEE 118 bus System in comparison with standard curtailment based optimization technique to produce encouraging results.

In [1] market structures and functioning in smart grid is carried out. From load and demand response graph the generation cost optimization formula: ∑Ci = a(i)p^2+b(i)p +c(i) is used. The cost coefficients a, b, and c are calculated with the help of data collected from different renewable energy power systems. The data is implemented in cost optimization formula to get the best results for cost coefficients a, b, and c.

In [2] PSO load flow model using OPF2 function in IEEE 118 buses and IEEE 30 buses System cost optimization is carried out for the particular values of cost coefficients a, b, and c. The Total cost generation(F1) is noted for a healthy system.

In [3] PSO load flow model using OPF2 function in IEEE 118 buses and IEEE 30 buses System loss optimization is carried out for the particular values of cost coefficients a, b, and c. The Total generation and transmission loss (TL) is noted for a healthy system.

In [4]

**Chapter 2**

**Market structure and functioning in Smart Grid**

The Smart Grid is an eco-friendly optimization of the present grid endeavored to achieve operational excellence with high degree of reliability. The functional architecture proposed and implemented are based on some basic modification of the present grid organization for proper management of distributed generation with renewable energy sources, improvement of sustainability with self-healing activities like congestion, power quality management and encouragement of price responsive demand reduction. The profusion of these activities employs extensive bidirectional communication between wholesale markets/transmission operation and retail markets/distribution operations. Fig. 1 depicts one such architecture enabling the system operator to not only utilize the generator information, but is also to make itself capable of incorporating the demand response of consumers aggregated by local entities like Regional Transmission Organization (RTO), historical and forecasted data, Available Transmission Capacity (ATC) margins etc. Efficient employment with these new resources as wholesale market product, Independent System Operator (ISO) will be able to reach the furthest corners of the network from generation to load end to maintain profound operating conditions under the worst possible states of the system. In this context ISO will be able to identify the state variable creating imbalance in the power market to de-standardize its operations. The price responsiveness of the state variables of modern power markets has been elaborated in the following section.

**The proposed price responsive OPF model**

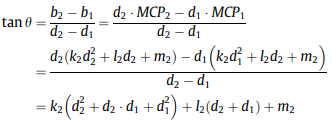
***Price sensitivity of demand***

The price responsiveness of demand has become an incredible input to the OPF algorithms for their load peak shaving capability in high price conditions. Effective deployment of this resource may lead to the solutions of modern day power network tribulations like network congestion, voltage instability and perturbations in dynamics in power market. The demand elasticity of price is, hence as depicted in an important parameter to be considered for Optimal Power Flow. With the assistance of smart metering this product can be incorporated in optimization to achieve distinction in operating conditions and welfare of the market participants. As shown in Fig. 2, a demand with a marginal benefit above the marginal price will lead to an expansion in consumption until the equilibrium is reached. In Fig. 2a A–B–C represents the bid curve at a particular hour, while X–Y its tangent. The price responsive demand curve (Fig. 2b) shows the nature of the consumer towards price volatility corresponding to the bids. From the bid curve the willingness to pay of the consumers can be determined as

willingness to pay = tan Ɵ



where d1, d2...etc. are the power demands and the bid curve is expressed as a function of demand such as f(di). The Market Clearing Price (MCP) corresponding to each point of the bid curve have been plotted in Fig. 2a and b. In this figure it has been assumed that b1 = d1. MCP1, b2 = d2 . MCP2, b3 = d3 . MCP3. Let us assume that the two curves are fitted with two different polynomials. k1x^2 + l1x + m1 represent the bid curve while k2x^2 + l2x + m2 represent the price responsive curve where k1, l1, m1 are the coefficients of bid curve and k2, l2, m2 are the coefficients of price responsive curve. Now mapping willingness to pay into price responsiveness of demand



The willingness to pay is as sensitive to bid curve as is to price responsive curve. Hence, inclusion of demand response or price responsive characteristics into OPF not only incorporates the price dependent consumption characteristics but also involves the willingness to pay of the consumers for a particular alteration in price. In the present work load demand is also scheduled like generation, the load curtailment becomes willingness to pay dependent and involves the consumer more into OPF. In every hour (or a specified period) the consumer with the assistance of smart metering, will be able to modify his stand in the power market enabling Independent System Operator (ISO) to regulate curtailment depending on ‘‘willingness to pay’’ of the consumers.