STUDY THE IMPACT OF RENEWABLE INTEGRATION, WEATHER VARIATION AND LOAD MODELS ON ENERGY MANAGEMENT OF TRANSMISSION NETWORKS

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

ELECTRICAL ENGINEERING

(With Specialization in Power System Engineering)

By

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CANDIDATE DECLARATION

I hereby declare that the work presented in this thesis, entitled **"Study the Impact of Renewable Integration, Weather Variation and Load Models on Energy Management of Transmission Networks"** in partial fulfillment for the award of the degree of **Master of Technology** with specialization in **"Power System Engineering",** submitted in **Department of Electrical Engineering, Indian Institute of Technology Roorkee, Roorkee** is an authentic record of my own work carried out during the period from May 2018 to May 2019 under the supervision of **Dr. N. P. Padhy, Professor, Department of Electrical Engineering, Indian Institute of Technology Roorkee, India.**

The matter embodied in the dissertation has not be submitted by me for the award of any other degree of this or any other institute.

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Place: Roorkee

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CERTIFICATE

This is to certify that the statement made by the candidate is correct to the best of my knowlwdge and belief.

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Abstract

The demand of electricity is increasing day by day and conventional sources of electricity is very limited. Renewable energy is becoming very attractive source of electricity to meet the load and protect the environment. Power system of India is transforming towards integration of high renewable energy. The challenges in integration of renewable energy are its uncertain availability and old existing power network infrastructure. As demand is also uncertain, so renewable energy cannot meet the demand without any ancillary system.

Integrating some energy storage system with renewable energy system can solve uncertainty problem of renewable energy. To integrate more renewable energy upgradation of power system and lines are required. Most of the time transmission lines are heavily under loaded from its actual power handling capacity, as worst possible power handling capacity of line is considered while scheduling power to generators. Actual power handling capacity of line depends on many environmental factors.

In this work, The effect of integrating high renewable energy and increasing storage type units on fuel cost of conventional power generation and curtailment of renewable energy have been studied with a IEEE 14 bus system. For an old 75-bus transmission system of Uttar Pradesh (India) with integration of all recent proposed solar power plant in Uttar Pradesh, the scheduling has been done considering static and weather based dynamic line rating. As the actual loads have different voltage based real and reactive power demand, a voltage dependent dynamic (ZIP) load model has been considered here for load modeling. Scheduling with a penalty on overloading of line and penalty on voltage deviation from nominal voltage has been done with dynamic and static line rating to see the difference of minimum possible overloading of line with static line rating and dynamic line rating. With this scheduling strategy, high renewable energy can be integrated to an existing system with minimum upgradation of lines.

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NOMNECLATURE

DLR- Dynamic line rating

ED- economic dispatch

ESS- Energy storage system

LP- Linear Programing

MILP - Mixed integer linear programming

OPF- Optimal power flow

PSH – Pump storage hydro

PV- Photovoltaic

RE- Renewable energy

SLR- Static line rating

UC- Unit commitment

CHAPTER-1

Introduction

1.1 BACKGROUND

Fossil fuel is the major source of power generation since industrial revolution. Fossil fuels are limited in nature and causes very high carbon emission. Since last few decades, a huge carbon emission become a serious threat to our society. Day by day increasing pressure to protect the environment and conservation of energy, forcing to limit the use of fossil fuel for power generation. With the aim of fossil fuel conservation and environment protection, renewable energy are becoming very attractive source of electric power. Renewable energy is environment friendly source of power and reduces carbon emission and it can be substitute of fossil fuel. This is demand of day to increase the use of renewable energy in the modern electric power system. The world is talking and working very rapidly with the motivation of increasing the use of renewable energy. However, the cost of electricity from renewable source was not very cheap in early stage of development but the fuel cost in renewable energy production is zero and also the cost related to environment is also zero. The power cost from renewable source reduced over past year. According to a report, “Renewable power generation costs in 2017” of “International renewable energy agency (IRENA)” [1] Solar photovoltaic (PV) module price has decreased by 81% since 2009 and electricity cost from solar photovoltaic power project has reduced by 73% since 2010.The recent results of auction for power project of renewable energy to be commissioned in next few years confirms that the cost reduction trend in renewable energy field will continue through 2020 and beyond. The wind power generation is also increasing and its cost is decreasing per year. The steady decrement every year in cost of solar and wind energy equipment and technology making renewable energy a most competitive way to feed the new power generation needs. To make the grid economic, integration of high renewable energy in grid will be one of the best ways. Renewable power has major disadvantage is that it is uncertain in nature and these are not under the control of operator like conventional power generations. According to report of National renewable energy limited (NREL) [2] ministry of power, India is on a way to increase its installed capacity of renewable energy to 175 GW by 2022. Uncertainty of renewable energy makes it unreliable and force to power operators not to be more depended on renewable energy instead of convention thermal power plants. The issue of reliable operation of power system with high penetration of renewable energy with its uncertain behavior leads power engineers to do research in this field.

For integrating more renewable energy in power system network, it is required to upgrade the infrastructure of power system network. For more penetration of renewable energy, the power handling capacity of transmission line also should be increased. In normal conventional power system, the line rating is fixed for whole day and known as static line rating. The line rating depends on many environmental factors like temperature, wind speed, solar irradiance etc. By using these environmental factors, the line rating can be generated for whole day, which will vary for every period. This type of line rating is known as dynamic line rating. For most of the time dynamic line rating is higher than static line rating, because static line rating is the rating of line for worst atmospheric condition. By utilizing the concept of dynamic line rating and with proper communication channel, the penetration of high renewable energy is possible on existing power system network without upgrading the infrastructure.

1.2 OBJECTIVE

The objective of this work is to cost optimization of conventional power generators with integration of high renewable energy in existing power system with storage. This report is divided into two parts.

First part is about the effect of increasing RE integration in grid on the operation cost of conventional power generating systems and study the effect of energy storage system (pump hydro storage) on increased RE penetration. Also, effect of increasing storage on RE curtailment.

In second section, variation of atmospheric condition has been included in an existing power system, in this section effect of dynamic line rating (DLR) on generation scheduling has been shown. Also in this section voltage dependent (ZIP) load model is considered. This section is all about complete utilization of existing power system with dynamic atmospheric condition, and to increase renewable integration with dynamic line rating.

The objective proposed in first part has been implemented in 14 bus modified system of IEEE [3], consisting thermal, hydro, pumped storage hydro and wind energy system. The objective proposed in second section have been implemented of Uttar Pradesh state electricity board 75 bus system [4] with integration of solar power plants proposed in Uttar Pradesh.

CHAPTER-2

Theoretical Overview

2.1 CONVENTIONAL POWER SYSTEM

A power system is network of electrical equipment used to supply the electricity generated form generation center to the electricity consumers on a desired voltage and frequency. A power system can be defined in three major stages. first one is generating stage where generation of electricity takes place then comes transmission stage, this part consist of transmission towers and transmission lines, transfer of power from generating station to load center takes place in this stage and then comes distribution stage, here supply of electricity to its consumers takes place.

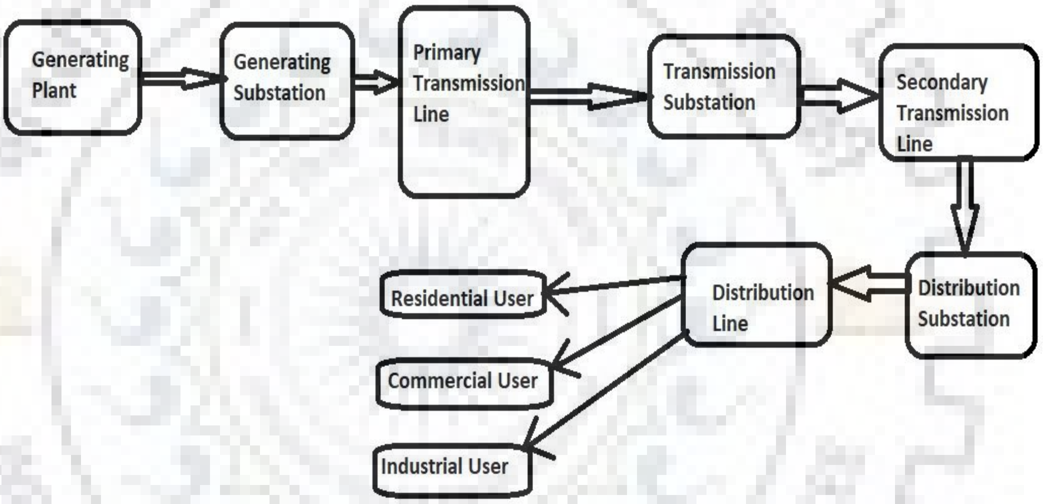

Figure 2.1: Conventional Power system

In generation stage, production of electricity takes place by converting any form of energy into electrical energy. The voltage level of electricity at this stage kept at 11KV usually. Insulation requirement and some practical design limitation bound the generation stage to 11KV.

For transferring power over a long distance, it is required to increase the voltage level. On high voltage transmission, the power delivering capacity increases and loss reduces. There are two stages of transmission system, Primary transmission system and secondary transmission system. The voltage level of primary transmission system is usually 200KV and above, it transfers power from power generating stations to secondary transmission system. Secondary transmission level voltages are 66KV to 132Kv and it transfers power to distribution center. Distribution system connects the electricity users with supply. It has also two stages – Primary distribution stage and secondary distribution stage. In primary distribution stage voltage level stepped down to 11KV or 33KV from 66KV or 132KV. Then it feeds to distribution transformer to bring the voltage level 415V for 3-Phase and 230V for single phase and feeds to domestic users. Some industrial and commercial loads are directly connected to primary distribution system at 11KV or 33KV.

2.2 MODERN POWER SYSTEM (SMART GRID)

Smart grid is combination of power system network, Information technology and telecommunication technologies. It improves the efficiency and reliability of the system and reduces the total expenditure. It automatically protects, optimizes and monitors all the interconnected elements with centralized network and distributed energy generators. Smart grid combines the electrical transmission and distribution systems with information and communication system. It schedules all the power generators and distributed renewable generators in a reliable and secure way to meet the load demand in an economic way. It provides two-way communications with utility and consumers to use the available energy in a smarter way.

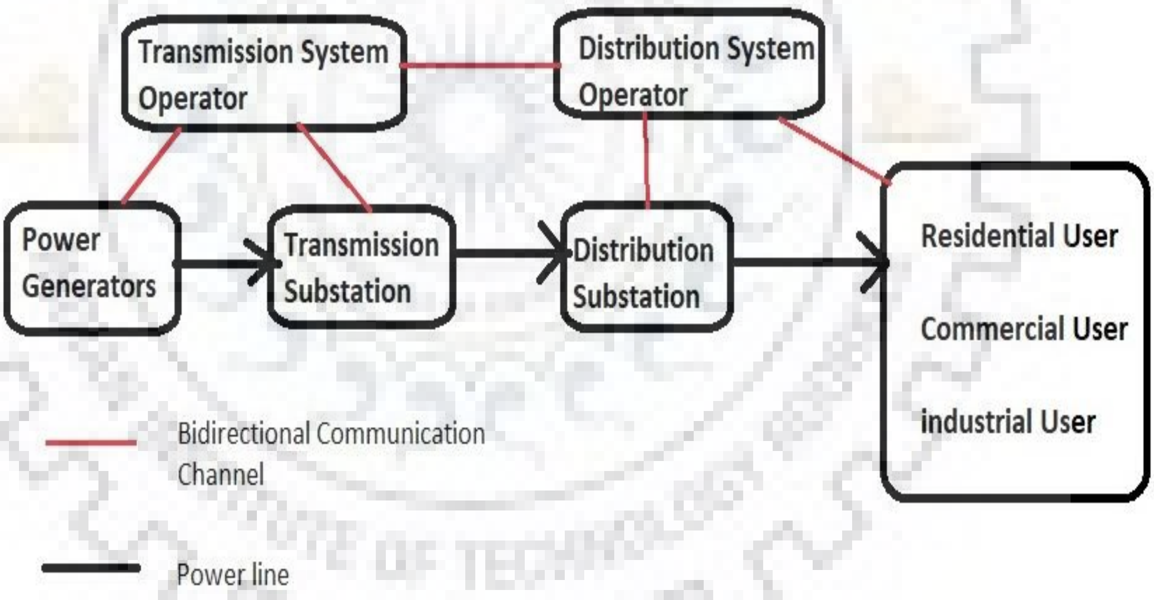

Figure 2.2: Modern Power system

2.3 ECONOMIC LOAD DISPATCH (ELD)

Economic load dispatch is a methods to schedule generators connected to power system for generation at each particular time with minimum operating and running cost, so that it meets all the load demand without violating constraints of generators. Problem of ELD can be defined as minimization of generation cost of set of generators with meeting all load demand. Scheduling the generation with ELD reduced the generation cost significantly. Traditional ELD was based on incremental cost of each generator. [5]

Objective function of ELD

$$\min(\sum_{i=1}^{N} F_i(P_i)) \tag{2.1}$$

Subject to constraints-

$$P_{min} < P_i < P_{max}, \qquad i = 1,2 \dots \dots . N \tag{2.2}$$

$$\sum_{i=1}^{N} P_i = P_d + P_{loss} \tag{2.3}$$

where $F_i(P_i)$ is cost of generation of power from i^{th} generator. P_i is power scheduled to i^{th} generator. P_{min} and P_{max} are minimum and maximum limit of i^{th} generator. P_d and P_{loss} are total power demand and power loss. The above mentioned ELD technique solves the scheduling problem for thermal or hydro-thermal power generation.

In modern smart grid ELD problem is solved with the help of pre-designed program. Many power system optimization techniques are available to solve scheduling problem in smart grid like Ant search, Tabu search, Particle Swarm optimization, Genetic algorithm etc. These techniques takes all the data of power system network like RE generation forecasted data, load forecasted data, Voltage of each bus etc. with communication channel and gives the result of ELD problem by satisfying all the constraints.

2.4 OPTIMAL POWER FLOW (OPF)

Optimal power flow is a method to decide the variables of power system network so that power flowing in a line should not exceed the rating of that line and voltages at each bus should be in a desired range. The objective of OPF is to minimize the losses of line and meeting all the security constraints of system. It includes voltage bound constraint, line flow limit constraint and power angle bound constraint. [5]

ELD and OPF simultaneously used for scheduling of power generators to meet the load demand with meeting all the generators and security constraint of power system at a minimum possible cost.

Lie flow limit constraint-

$$-S_k^{lim} < \sqrt{(P_k^2 + Q_k^2)} < S_k^{lim} \tag{2.4}$$

Voltage and power angle constraint

$$V_i^{min} < V_i < V_i^{max} \tag{2.5}$$

$$\delta_i^{min} < \delta_i < \delta_i^{max} \tag{2.6}$$

P_k , Q_k and S_k are real power flowing, reactive power flowing and MVA rating of k^{th} line. V_i, $V^{min}{}_i$ and $V^{max}{}_i$ are bus voltage, minimum allowable voltage and maximum allowable voltage for i^{th} bus.

Linear programming method is a common method to solve ELD and OPF problems. It easily handles all the equality and inequality linear constraint. Non-linear objective function and constraints can be handled by linearization of equations.

2.5 THERMAL POWER GENERATION

Total operation cost of thermal power generation is sum of production cost, startup cost and shut down cost. The production cost of thermal generation typically expressed as quadratic function of power output of generating unit. [11] $C_{i,j}$ is the production cost of of i^{th} unit in j^{th} time period. $C_{i,j}$ is function of real output power of that generating unit (P_i) and expressed as quadratic function of P_i . Output power P_i of thermal generating unit can be any value between minimum (P_{min}) and maximum (P_{max}) rated power i^{th} of generating unit.

$$C = \sum_{j=1}^{t}\sum_{i=1}^{n} C_{i,j} \qquad \$/hour \tag{2.7}$$

$$C_{i,j} = a_i P_{i,j}^2 + b_i P_{i,j} + c_i \tag{2.8}$$

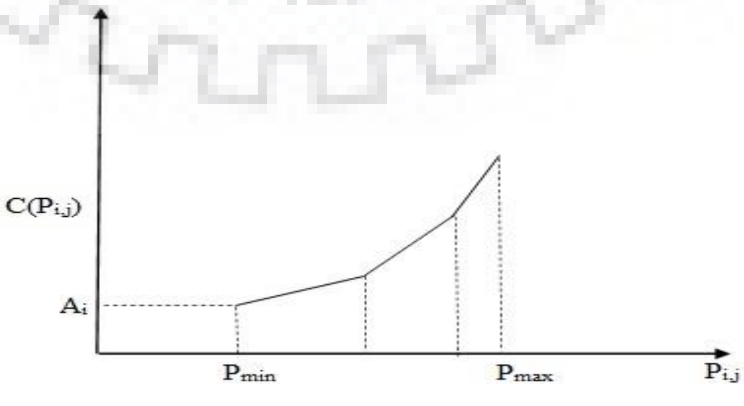

Figure 2.3: Piecewise linear cost function of thermal generator

Production cost function equation (2.8) is non-linear function of $P_{i,j}$, For cost optimization by linear programming technique, production cost should be linear. a_i , b_i and c_i are cost characteristic coefficient of thermal power generator. Production cost function can be converted to piecewise linear production cost as shown in figure (2.3). In figure (2.3), non-linear production cost approximated to linear function by breaking it into three segments, and expressed as equation (2.9).

$$C_i = A_i + \sum_{l=1}^{NL} F_{i,l}\, \delta_{i,l} \tag{2.9}$$

In equation (2.9) , A_i is production cost of i^{th} generator at minimum output power of that generator (P_{min}), NL is number of segments in piecewise linear production cost, $F_{i,l}$ is slope of l^{th} segment of i^{th} generating unit and $\delta_{i,l}$ is real power of l^{th} segment.

Constraints-

$$P\_th_i^t - P_{th}{}_i^{t-1} \le r_{up}^i . \Delta t \tag{2.10}$$

$$P\_th_i^{t-1} - P\_th_i^t \le r_{down}^i . \Delta t \tag{2.11}$$

Equation (2.10) and equation (2.11) are ramp up and ramp down rate constraint of thermal generator. $P\_th_i^t$ is power output of i^{th} generator on hour t, $r_{up}{}^i$ and $r_{down}{}^i$ are ramp up and ramp down rate of i^{th} generator respectively.

$$P_i^{min} \le P\_th_i^t \le P_i^{max} \tag{2.12}$$

Equation (2.12) bounds the output of thermal generator between its maximum and minimum limit.

2.6 HYDRO POWER GENERATION

There is no fuel cost in hydro power generation, costs in hydro power generation are only related to maintenance, operation and wages of workers. Power generated by hydro power generator depends on water discharge rate of reservoir. The water level of reservoir should be maintain in a limited range so it not feasible to run a hydro power plant on its rated capacity always. Also, water discharge rate is bounded. Power output of hydro power plant depends on water discharge rate, Power output is non-linear function of water discharge rate and expressed as equation (2.13). [12]

$$P\_hyd_{i,j} = U_{i,j}(\alpha_i Q_{i,j}^2 + \beta_i Q_{i,j} + \gamma_i) \tag{2.13}$$

$P\_hyd_{i,j}$ is output power of i^{th} hydro generating unit in j^{th} time period, $Q_{i,j}$ is water discharge rate from reservoir for i^{th} hydro generating unit in j^{th} time period, α, β and γ are power generating coefficient of hydro generator. $U_{i,j}$ is binary variable for on/off status of generating unit. *P_hyd* expressed as piecewise linear function of water discharge rate is shown in figure (2.4).

Power equation from piecewise linear curve expressed as equation (2.14).

$$P\_hyd_{i,j} = U_{i,j}(P_{min,i} + F1.q1_{i,j} + F2.q2_{i,j} + F3.q3_{i,j}) \quad (2.14)$$

P_{min} is power generated by hydro power plant of minimum water flow rate. *F1*, *F2* and *F3* slope in piecewise linear curve and *q1*, *q2* and *q3* are water flow rate in respective segment.

$$P_{min} = Q_{min}.F1 \quad (2.15)$$

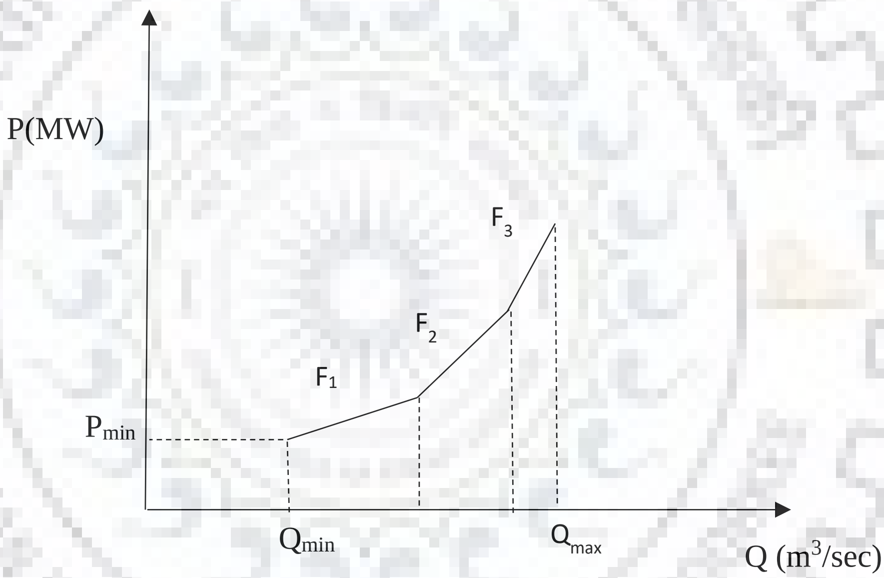

Figure 2.4: Piecewise linear power output curve for hydro generator

Constraints-

$$Q_i^{min}.U_i^t \leq U_i^t.(Q_i^t) \leq Q_i^{max}.U_i^t \quad (2.16)$$

$$V_{min} \leq V \leq V_{max} \quad (2.17)$$

$$V_{t=24} = V_f \quad (2.18)$$

Equation (2.16) is constraint of water flow rate of hydro power plant. Q_i^t is water flow rate of i^{th} unit on t^{th} time and U_i^t is binary variable for on/off status of unit and it is integer and binary type variable. Equation (2.17) and (2.18) are constraint of reservoir for minimum and maximum water level of reservoir and for final water level of reservoir.

2.7 PUMPED STORAGE HYDRO

The imbalance cost related to the variable nature of the RE generation reduces the expected profit of these plants. If storage type units support these plants, the imbalance cost will be significantly reduced and the expected profit will increase. There are many types of storage plants like Battery storage, Compressed air energy storage (CAES), Pumped hydro storage etc. Among all PSH is best suitable technique for storage of energy on transmission level. If there is a surplus energy compared with demand, it should be used to pump the water to the upper reservoir. If there is deficit generation, the pump-storage unit should in generating mode. Also, it will support the uncertainty in load variation and make system stable with ramp constraint of conventional power generators. Power generation and pumping equation can be defined same as hydro power plant. Power output of PSH plant also non-linear function of water flow rate as hydro power plant. The power output in this case could be positive as well as negative also. Positive power indicates that PSH plant is working in generating mode, in this case water flows from upper reservoir. Negative power indicates that PSH plant is working in pumping mode and pumping water to upper reservoir. [13]

$$P\_psh_{i,j} = U'_{i,j}(\alpha'_i Q'^2_{i,j} + \beta'_i Q'_{i,j} + \gamma'_i) \quad (2.19)$$

$P\_psh_{i,j}$ is output power of i^{th} PSH generating unit in j^{th} time period, $Q'_{i,j}$ is water discharge rate from reservoir for i^{th} PSH unit in j^{th} time period, α', β' and γ' are power generating coefficient of PSH generator. $U'_{i,j}$ is binary variable for on/off status of generating unit.

Constraints-

$$Q_i^{gen\_min}.U_i^{gen\_t} \le U_i^{gen\_t}.\left(Q_i^{gen\_t}\right) \le Q_i^{gen\_max}.U_i^{gen\_t} \quad (2.20)$$

$$Q_i^{pum\_min}.U_i^{pum\_t} \le U_i^{pum\_t}.\left(Q_i^{pum\_t}\right) \le Q_i^{pum\_max}.U_i^{pum\_t} \quad (2.21)$$

$$V_{min}^{PSH} \le V_i^{PSH} \le V_{max}^{PSH} \quad (2.22)$$

$$V_{t=24}^{PSH} = V_f^{PSH} \quad (2.23)$$

$$U_i^{gen\_t} + U_i^{pum\_t} \le 1 \quad (2.24)$$

Equation (2.20) and (2.21) are constraint for water flow rate of PSH system in generating and pumping mode respectively. $Q_i^{gen\_t}$ and $Q_i^{pum\_t}$ are water flow rate in generating and pumping mode. $U_i^{gen\_t}$ and $U_i^{pum\_t}$ are binary variable for on/off status of PSH unit in generating and pumping mode and it is integer and binary type variable. Equation (2.22) and (2.23) are constraint for water level in upper reservoir of PSH unit. Equation (2.24) is constraint of PSH unit, which bounds it to work in either generating or pumping mode at a time *t*.

2.8 WIND ENERGY SYSTEM

Wind energy is a kinetic energy that is associated with large movement of air. These movements are caused due to uneven heating of atmosphere by the sun, which results in differences in temperature, pressure and density of air. There are however difference between solar and wind energy, solar energy is available during the day only while wind energy may be available throughout the 24 hours period of the day. Wind energy systems converts the kinetic energy available in the moving air into mechanical energy and then into electrical energy by wind turbine.

For extraction of electrical energy from wind, the speed of wind must be between cut in speed and cut out speed. Cut in speed is the minimum speed of wind required to generate power by wind turbine. Cut out speed is the maximum wind speed at which wind turbine can operate, above cut out speed of wind it not feasible to operate wind turbine. At rated speed of wind, it will give rated power output. [14]

For a given wind speed input, the wind power output is expressed as,

$$P_{WT} = \begin{cases} 0 & for\ v < v_i\ and\ v > v_o \\ P_r\left(\dfrac{v - v_i}{v_r - v_i}\right) & for\ v_i \le v \le v_r \\ P_r & for\ v_r \le v \le v_o \end{cases} \tag{2.25}$$

Where P_{WT} is wind power output of wind energy generator, v is wind speed in (m/sec), and v_r, v_o, v_i, are rated, cut out and cut in speeds respectively.

$$P_{wind} \le P_{wind}^{max,t} \tag{2.26}$$

Equation (2.26) is constraint for wind power (P_{wind}), Wind power scheduled at time *t* should be less than maximum wind power available at time *t* ($P_{wind}^{max,t}$).

2.9 SOLAR ENERGY SYSTEM

The basic principle of solar energy system is to convert light into electric energy. Solar system is array of photovoltaic module and work on principle of photoelectric effect. In modern days demand of clean energy leads towards installment of large solar power plants and solar parks. Solar parks are ultra-solar power generating station usually in the range of MWs and are spreads in several km^2. Solar power plants are of two types grid connected and off grid. Grid connected solar power stations are connected with power system grid with power electronics converters. Off grid solar power plants are usually installed with other renewable generators and storage system for reliable operation. The generation of power from solar depends on solar irradiation and temperature. Also, PV arrays of solar power station equipped with solar tracking system for maximum efficiency. [15]

Generation of power from solar power plant is given by,

$$P_{PV} = \begin{cases} P_{sr}.\left(\dfrac{G^2}{G_{std}.R_c}\right); for\ 0 < G < R_c \\ P_{sr}.\left(\dfrac{G}{G_{std}}\right);\ for\ G > R_c \end{cases} \tag{2.41}$$

P_{PV} is power generated by solar power station.

G : Forecast of solar irradiation in W/m^2

G_{std} : Standard solar irradiation, for a standard environment set as 1000 W/m^2

R_c : A certain irradiation point set as 150 W/m^2

P_{sr} : Rated power output of solar generator

$$P_{PV} \leq P_{PV}^{max,t} \tag{2.42}$$

Equation (2.42) is constraint for solar power (P_{PV}), Solar power scheduled at time *t* should be less than maximum Solar power available at time *t* ($P_{PV}^{max,t}$).

2.10 SUMMARY

In this chapter, theoretical overview of conventional and modern power system have been discussed. The basics economic load dispatch method and optimal power flow for both the power system is discussed. After that the cost function, power output function and all constrains of different type of conventional and renewable power generation have also been narrated. This chapter gives overview of the infrastructure of power system and all the function related to economic load scheduling to generators.

CHAPTER-3

Literature Review

Farag *et al.* [5] discussed about economic scheduling problem of real power and reactive power. They have shown many constraints related to generator and line in this problem and used Newton Raphson iterative technique to solve the scheduling problem. They have solved scheduling problem for two models 10-bus model and 30-bus model. Also for one model, they have used linear programming method for generation cost optimization.

Bedekar *et al.* [11] shown unit commitment of thermal power generators. The scheduling of active power for thermal generator done in this work. In this work Genetic algorithm for unit commitment of thermal power generator has been developed and has been tested for different cases. For optimal operation, they have constrained the incremental cost of generators to be equal. A fitness function in genetic algorithm has been defined to accommodate different the increment cost constraint and load balance constraint. Here variable is scheduled power to generator and limit of power generation of generator is bounded with the help of lower and upper bound of variable.

Jong-Bae Park *et al.* [16] discussed a new approach to solve economic dispatch problem with non-smooth cost function. They have followed particle swarm optimization (PSO) technique to solve practical economic dispatch problem, because practical system has always non smooth cost function. In this work, a modified PSO technique has been suggested to deal with all equality and non-equality constraints. A dynamic search space reduction strategy also introduced to accelerate the process of optimization. To show the effectiveness and speed of this method a comparison with conventional economic dispatch problem technique like genetic algorithm, Tabu search also shown.

Carrión and Arroyo [17] proposed mixed integer linear programming (MILP) technique to solve economic dispatch and unit commitment (UC) problem of thermal power generator. In this work, they have solved UC problem for conventional centralized power system. Binary variable in MILP technique is included as variable for ON/OFF status of generator. MILP is a technique, which solve optimization problem with linear objective function and constraints having binary and non-binary variables. Binary variable in this type of problem makes easy to handle time dependent startup cost in objective function. This method is very efficient to solve large-scale cost optimization problem.

Diniz and Souza [12] solved the short-term scheduling problem for hydro and thermal generators. In this work, they have considered about river level constraint and ramping rate of hydropower generators. Concept of river routing and level of stream of river also discussed in this work. This work proposed linear programming model for hydrothermal scheduling and represents linear river level constraint. This approach for hydrothermal dispatch has been solved for an independent power system operation of Brazil.

Guedes *et al.* [18] A compact MILP based optimization method has been proposed in this work. Short term hydropower scheduling has been solved. In this work piece wise linear approximate model proposed for MILP formulation fast and easy optimization. Integer binary have been considered for ON/OFF status of hydro generator. Water flow rate and water head level are two different variables. Water discharge rate decides the power output and power output I quadratic function of water discharge rate, which is linearized with piece wise linear model. Water head variable is restricted with upper and lower bound.

Parasstegari *et al.* [13] studied the joint operation of renewable energy with energy storage system. In this work, uncertainty of wind energy is coordinated with pumped storage hydro system. The availability of renewable energy is very uncertain and demand of energy is also uncertain, so meet the demand in a reliable manner with renewable source ancillary service is required. In this work, it is shown that the energy storage system with renewable can work as ancillary service and meet the demand when renewable generation is low. The power dispatch problem for IEEE 118 bus standard system with wind energy and pumped energy storage system has been solved.

Biswas *et al.* [19] a multi-objective environmental economic dispatch problem is formulated in this work. Here a method of economic dispatch has been proposed which includes thermal, small hydro, wind and solar system. Security constraints like voltage and transmission line power flow limit have been considered here. Cost related to emission due to thermal power generation is included in cost optimization objective function. Objective is to minimize the total cost, which includes all the cost related to power generation and penalty cost due to emission in environment. This forces to use more renewable energy and result shows effects penetration of high renewable energy on total cost and on emission from thermal power plant.

Nassar and Abdella [20] studied about effect of replacing 20% thermal power plant with renewable energy on power system of Egyptian Electricity holding company. This study has been done in three different stages – in first scenario RE integration is 2%, in second it is 14% and in third it is 20%. Results of this work shows that deviation in frequency is increases with increment in RE integration in system and emission of harmful gases from thermal power plants reduces. Upto 20% RE integration frequency is in safe limit. This work suggests frequency deviation due to replacement of thermal power with RE can be reduces with increasing governor gain and increasing ramp up and ramp down rate of conventional power plants.

Yaowen Yu *et al.* [21] Uncertainty in power system reduces its reliability. In this work contingency uncertainty and uncertainty of renewable energy has been considered simultaneously. IEEE 118 bus modified system has been taken with high renewable penetration and a contingency constrained unit commitment method has been developed to solve economic dispatch problem. This work develops an interval optimization approach to handle both transmission contingency and uncertainty of renewable energy.

Uski [6] discussed about method to estimate dynamic line rating (DLR) and economic benefits of DLR. For the reliable operation of power system operates on static line rating, which is worst possible rating of transmission line. The actual power handling capacity depends on many atmospheric conditions. In this work, it is suggested that by the use of DLR, the congestion of system can be handled in a smart manner without compromising to any security constraints. It is advisable in this work to forecast the weather condition 12-36 hours before the operation. The economic benefits on Sweden and Finland transmission system for a day ahead scheduling has been shown in this work.

Simon *et al.* [7] proposed a method to determine DLR with the use of geographical information system (GIS). In this, work the effectiveness of DLR with GIS and weather data shown on security constrained unit commitment problem. The use of GIS for determination of line rating increases effectiveness. The effect of wind speed and direction has greater impact on line rating. This proposed method has been tested on IEEE 30 bus system of Virginia State of USA with the geographical data obtained from Google Earth global GIS system and results shows better economic and improved security.

Wallnerström *et al.* [8] discussed about a general calculation model for DLR and specially impact of wind speed on wind power generation and on line rating. This work shows that with the speed of wind the power generation of wind generator increases and also line raring increases which increases the penetration level of wind generator in the system. In this work the penetration of wind energy has been done with static and dynamic line rating both and results shows that DLR has significantly more penetration level of wind energy.

Sadeghi and Sarvi [9] discussed ZIP model of load. In power system actual load depends on actual voltage it cannot be constant. It shows, load can be categories in three category- constant power, constant impedance and constant current. Z, I and P coefficient of load can be determined by two approaches, first by categorizing type of load connected and characteristic of load and second by measurement based approach by varying voltage from 0.90 to 1.10 per unit and study the behavior of load. In this work the coefficients of load is determined by measurement base approach and following least square optimization technique. This paper represents active and reactive power as quadratic function of actual voltage and nominal voltage.

Bokhari *et al.* [10] determined Z, I and P coefficient of load with an experimental approach. These coefficients are dynamic load coefficient. In this work, modern load has been categories in three sections Residential, Commercial and Industrial load. Industrial equipment and household equipment of different location has been tested by varying voltage from 1.0 per unit to 0 and again 1.0 with step of 3 volts to obtain I-V, P-V and Q-V characteristic. All different type of load has been tested and a table has been prepared to determine Z, I and P coefficient. In this work it is found that modern day load characteristics changed significantly than 10 years ago.

CHAPTER-4

Energy Management For RE Integrated Transmission System with Storage

4.1 INTRODUCTION

This work is aimed to minimize the cost of thermal power generation and study the effect of increasing storage system and increasing RE penetration on curtailment of RE and on cost of thermal power generation, assuming cost of generation of hydro plant and renewable zero. Line losses are ignored and line flow limit constraint, constraint related to hydro- water flow limit, reservoir level, ramp rate of generation, constraint related to thermal power generator- ramping up, ramping down rate, constraint related to PSH plant – minimum up and minimum down time, water flow rate, reservoir level constraint are considered in this work.

4.2 PROBLEM FORMULATION

Objective function

Scheduling problem is formulated in linear programming technique for its easy way of execution. The objective of proposed system is to minimize the cost of thermal power plant generation. It is considered that thermal power plant is running continuously for 24 hours of the day. The cost function of thermal power generation is given in equation (2.8) and linearized in equation (2.9).

$$Z = minimize \left(\sum_{i=1}^{t} \sum_{j=1}^{N_t} C_{i,j} \right) \tag{4.1}$$

$C_{i,j}$ is the cost function of thermal power generation as described in equation (2.8). Objective is to reduce power generation cost from thermal power plant.

The objective function equation (4.1) is subject to various constraints of generating units. Constraints related to thermal power plant is in equations (2.10)-(2.12), hydro power plant is in equations (2.16)-(2.18), PSH unit is in equations (2.20)-(2.24) , wind energy system is in equation (2.26), line flow limit constraint mention in equation (4.3) and load balance constraint in equation (4.4).

By assuming transmission line is purely reactive, difference of load angle of bus very small and per unit bus voltage 1, power flowing in the line between bus *i* and bus *j* is given by equation (4.2).

$$P_{ij} = \left(\frac{\theta_i - \theta_j}{x_{ij}}\right) \tag{4.2}$$

Power flowing in any line should not be more than its defined limit, otherwise this may lead to overheating in line and damage of line.

$$\left(\frac{\theta_i^t - \theta_j^t}{x_{ij}}\right) \leq P_{ij}^{limit} \tag{4.3}$$

Equation (4.3) is constraint to limit the power flowing in line below its limit. Θ_i^t is voltage angle of i^{th} bus at time t, x_{ij} is line reactance of line connecting bus i and bus j and P_{ij}^{limit} is maximum real power capacity of line connecting bus i and bus j.

$$\sum_{i=1}^{N_t} P\_th_i^t + \sum_{i=1}^{N_{hyd}} P\_hyd_i^t + \sum_{i=1}^{N_{psh}} P\_psh\_g_i^t - \sum_{i=1}^{N_{psh}} P\_psh\_p_i^t + \sum_{i=1}^{N_{wind}} P\_wind_i^t = \sum_{i=1}^{N_{bus}} P\_load_i^t \quad ; \quad for\ t = 1,2 \ldots 24 \tag{4.4}$$

Equation (4.4) is constraint for load balance at a time *t*. Here *P_th, P_hyd, P_psh_g* and *P_wind* are power scheduled to Thermal power plant, Hydro generator, PSH in generating mode and Wind energy system respectively. N_t, N_{hyd}, N_{psh} and N_{wind} are number of Thermal generator, hydro generator, PSH unit and wind energy system. *P_psh_p* is power used by PSH in pumping mode at time *t*. *P_load* is load at i^{th} bus at time *t* and N_{bus} number of buses is system.

4.3 SOLUTION STRATEGY (MILP)

There are many methods of optimization, among them I found branch and bound method simple. Branch and bound method is followed for cost optimization. Mixed integer linear programming (MILP) is a technique of optimization, which follows the concept of branch and bound method.

A code is developed for cost optimization in MATLAB based on MILP technique, considering all the constraint mentioned above. All the constraints have been linearized in this code.

Structure of MILP for minimization

$$Minimize\ (f(x_1, x_2, x_3 \ldots \ldots x_n)) \tag{4.5}$$

Subject to following constraints

$$A_1x_1 + A_2x_2 + \cdots + A_nx_n \leq b_1 + b_2 + \cdots + b_n \tag{4.6}$$

$$A_{eq1}x_1 + A_{eq2}x_2 + \cdots + A_{eq3}x_n = b_{eq1} + b_{eq2} + \cdots + b_{eqn} \tag{4.7}$$

$$lb_i \leq x_i \leq ub_i \quad ; \; for \;\; i = 1,2 \ldots \ldots . . n \tag{4.8}$$

$$x_2, x_5, x_8, x_{n-2} = integer \tag{4.9}$$

Equation (4.5) represents objective function for minimization, equation (4.6-4.9) are constraint in linear form, Equation (4.6) is inequality constraint, Equation (4.7) is equality constraint, Equation (4.8) represents upper and lower bound of variable and equation (4.9) bounds that some variables should be of integer type only.

There are many non-linear terms in scheduling problem in the form of *U.x*, where *U* is a binary variable which can be 0/1 and *x* is variable that can be any value between x_{min} to x_{max}. This non-linear should be linearized for applying MILP technique of optimization.

Linearization procedure of *U.x* is given below-

$$\begin{gathered} Let\ U.x = Z \\ Z \leq U.x_{max} \\ Z \geq x_{min} - (1-U).x_{max} \\ Z \geq 0 \end{gathered} \tag{4.10}$$

4.4 TEST SYSTEM

IEEE modified 14 bus system shown in figure 4.1 has been taken for study the result. Standard loads of each bus of IEEE 14 bus system is changed to 50% - 150% for 24 hours randomly. Line data of IEEE 14 bus system is given in Appendix [A]. Four cases are analyzed here with three different Thermal, Hydro, PSH, and Wind energy system combinations. Total demand for 24 hours is shown in figure 4.2.

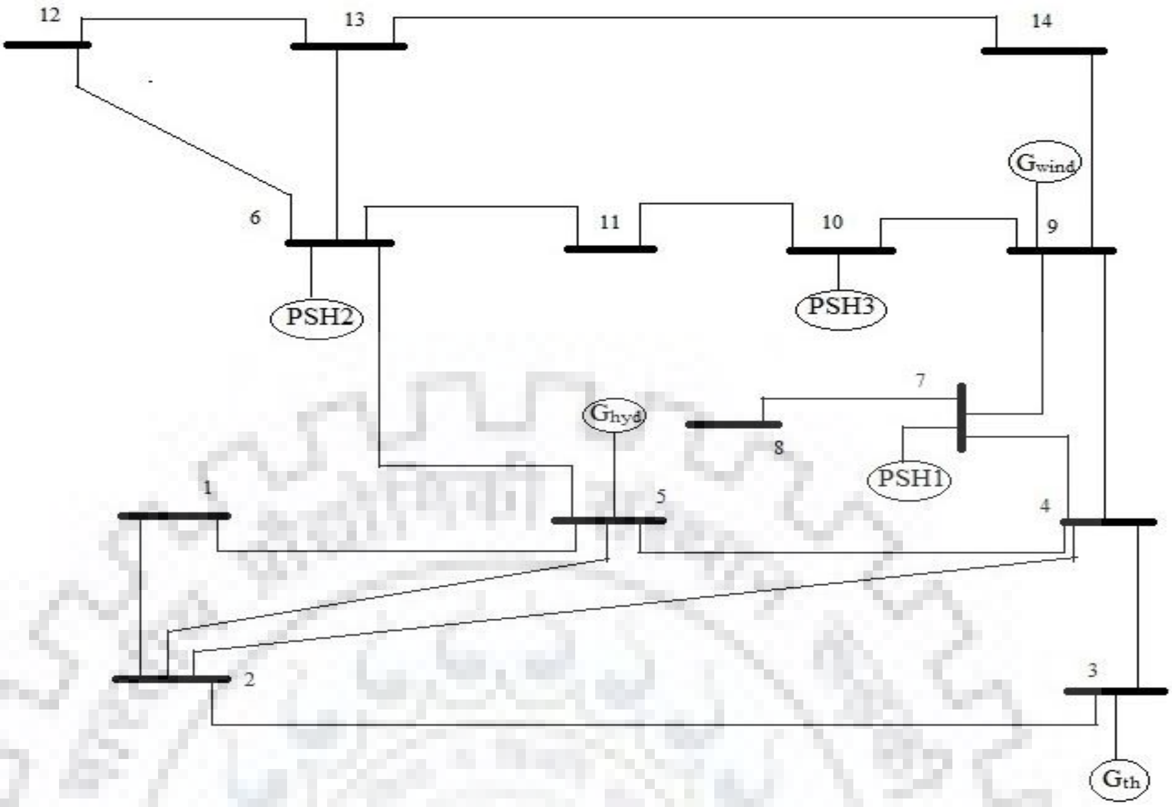

Figure 4.1: IEEE modified 14-bus system

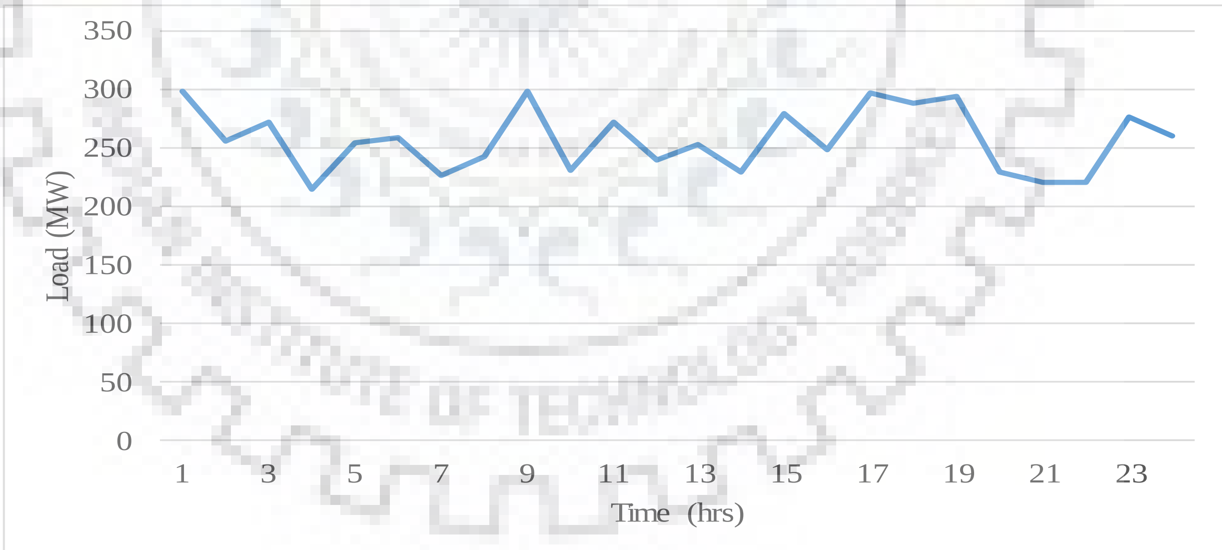

Figure 4.2: Load profile IEEE 14 bus system

Data of all generating and storage unit are collected from many sources. Thermal power plant data collected from [17], Hydro power generating unit from [22], PSH unit data from [13] and wind power forecasted data from [14].

Table I: Thermal power generating unit data for IEEE 14 bus system

Unit	*A*	*B*	*C*	P_{min} (MW)	P_{max}(MW)	*Ramp rate(MW/min)*
G1	0.005	2.450	105	10	160	0.25
G2	0.005	3.510	44.1	20	80	0.25

Table II: Hydro power generating unit data for IEEE 14 bus system

Unit	*F1*	*F2*	*F3*	Q_{min} (m^3/sec)	Q_{max} (m^3/sec)	V_{min} (Hm^3)	V_{max} (Hm^3)	V_0 (Hm^3)	V_f (Hm^3)	W_i (Hm^3/hour)
G_hyd 1	2.1	2.0	2.3	36	50	121	256	217	217	0.18

In table III Q_{min} and Q_{max} are minimum and maximum water flow rate from reservoir, V_{min}, V_{max}, V_0, and V_f are minimum, maximum, initial and final water in reservoir and W_i is natural water inflow in reservoir.

Table III: Pumped hydro storage unit data for IEEE 14 bus system

Unit	*Reservoir upper limit* (Hm^3)	*Reservoir lower limit* (Hm^3)	*Reservoir initial volume* (Hm^3)	*Reservoir termination volume* (Hm^3)	*Lower discharge limit* (hm^3/hr)	*Upper discharge limit* (hm^3/hr)
PSH1	200	60	80	80	7	20
PSH2	150	50	55	55	5	15
PSH3	150	50	55	55	5	15
Unit	*Min. On time (hr)*	*Min. off time (hr)*	α'	β'	γ'	
PSH1	1	1	-0.025	2.5	0	
PSH2	1	1	-0.033	2.5	0	
PSH3	1	1	-0.033	2.5	0	

Table IV: Forecasted wind power data

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Wind (MW)	58.27	82.12	89.22	84.73	77.25	65.13	75.91	71.55	73.40	49.11	30.17	18.09
Hour	13	14	15	16	17	18	19	20	21	22	23	24
Wind (MW)	10.80	12.50	15.00	21.62	15	10.88	14.5	12.54	16.00	28.41	30.34	37.10

4.5 SIMULATED CASE STUDY

Four different scheduling problem have been solved to study the cost of thermal power generation and renewable curtailment on the 14 bus system described above.

- Case 1: 24 hour load scheduled with 2 thermal generating unit (G1 and G2), one hydro generating unit (G_hyd1) and one wind energy system.
- Case 2: Two thermal generating unit (G1 and G2) are connected at bus 3, one hydro generating unit (G_hyd1) is connected at bus 5, one PSH unit (PSH1) is connected at bus 7 and one wind energy system is connected at bus 9.
- Case 3 : In this case all generating units are connected same as case 2, and wind energy penetration is increased by 40%.
- Case 4 : In this case two more PSH system are connected on bus 6 (PSH2) and on bus 10 (PSH3) and wind penetration is same as case 3.

CASE 1: Scheduling Of Thermal, Hydro and Wind System

Scheduling for 24 hours load have been done with 2 thermal generator (G1 and G2), one hydro generator (G_hyd1) and one wind energy system, to study the cost of thermal power generation and curtailment of wind energy.

Figure 4.3 shows the power scheduled from each generating unit for this case and load profile for 24 hours. In this case, total cost for thermal power generation is $13254. Figure 4.4 shows the comparison between wind power available and wind power utilized. Here curtailment of wind power is very is high, which is not good for the system, and more power is scheduled from thermal power plan, which increases the cost and emission. This results shows without any storage system curtailment of RE will be very high. So in next case PSH unit is included to store the excess power available from RE and use when it is required. In this case, curtailment of wind power is 20.37%.

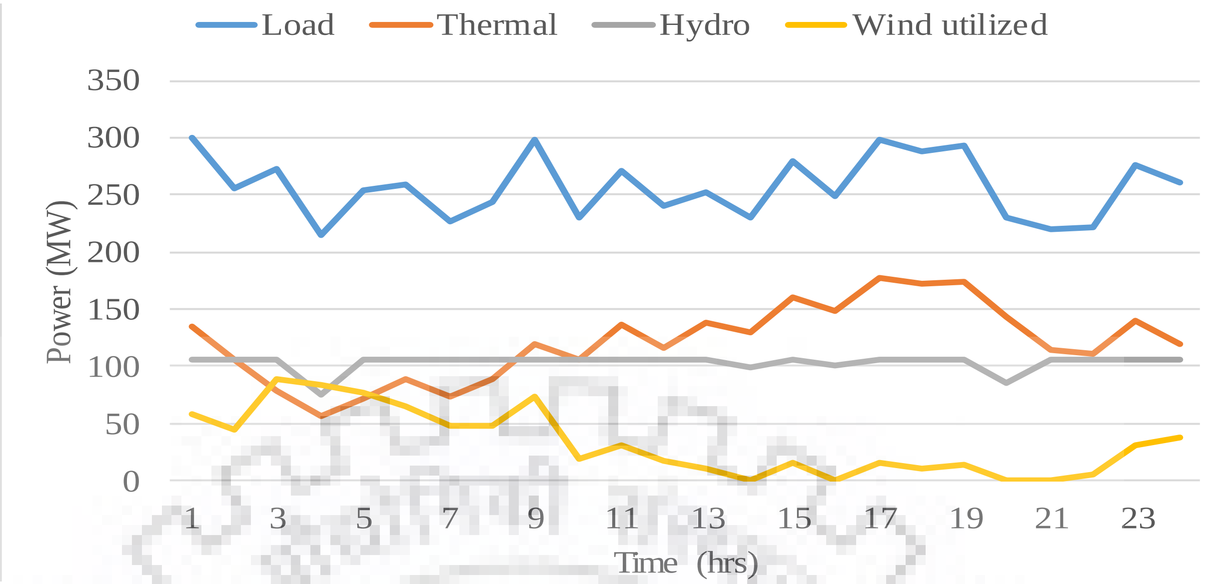

Figure 4.3: Power from each generating unit for case 1

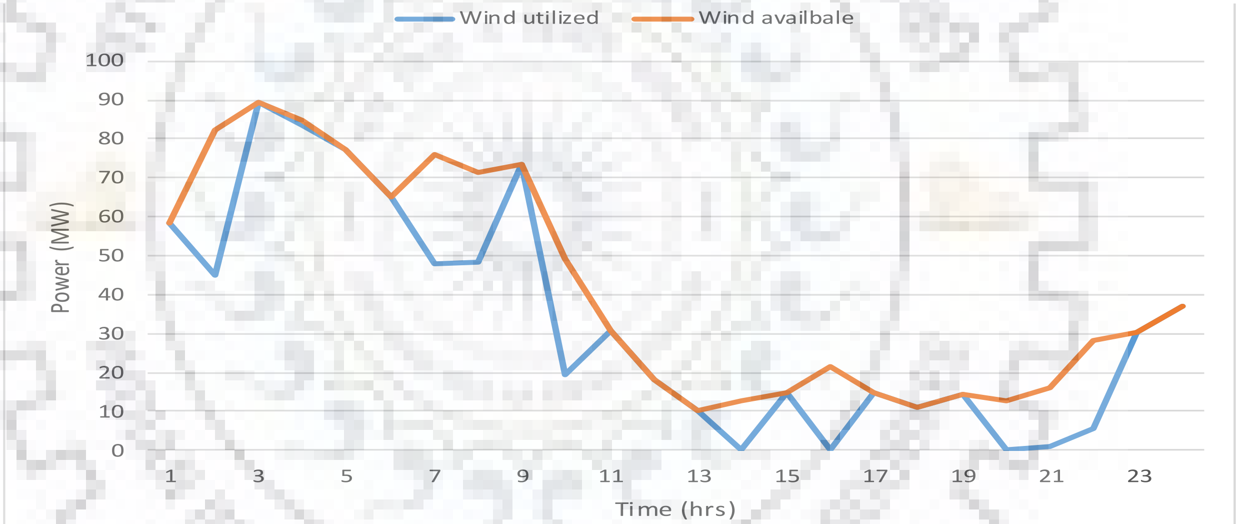

Figure 4.4: Available wind power vs Wind power utilized for case 1

CASE 2: Scheduling Of Thermal, Hydro and Wind System with One PSH Unit

Scheduling for 24 hours load has been analyzed on IEEE modified 14 bus system, with 2 thermal generator (G1 and G2) at bus 3, one hydro generator (G_hyd1) at bus 5, one PSH unit (PSH1) on bus 7 and wind system on bus 9. Power forecasted from wind is given in table IV, data of thermal, hydro and PSH system is in table I, table II and table III respectively. Load profile for 24 hours is shown in figure 4.2. Load profile is generated from standard IEEE 14 bus load data by varying load of each bus randomly 50% to 150% for 24 hours.

In figure 4.5 power scheduling from each generating unit and power used for pumping in PSH unit in case 2 is shown. In figure 4.5 it can be seen that PSH unit is working either for generating or pumping mode at a time. From 2nd hour to 9th hour power from wind is more comparatively, so in this period PSH unit is working in pumping mode most of the time and also generation from thermal is low in this period. From 17th to 21st hour wind power is low so in this period PSH is working in generating mode more. Cost of generation of thermal power plant in this case is $12616. In this case generation from thermal unit is reduced significantly as compare to case 1, which reduces the cost and emission.

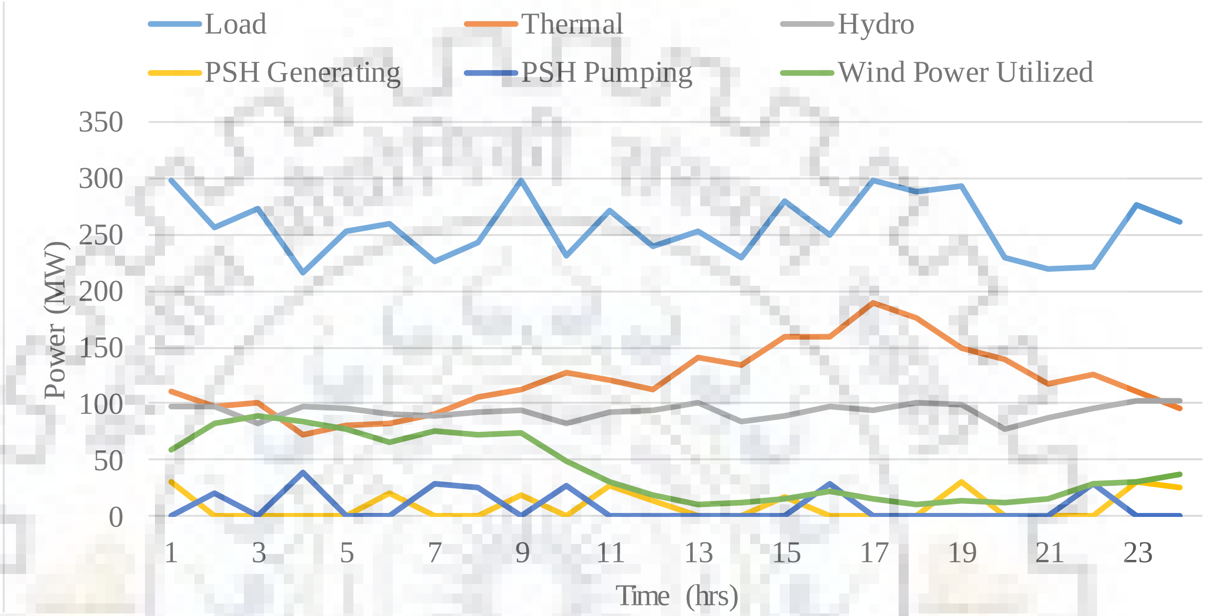

Figure 4.5: Power from each generating unit for case 2

Figure 4.6 shows the comparison between available wind power and utilized wind power, in this case, all the power is being utilize, and there is no curtailment of wind power in this case. This shows to utilize RE, storage unit should be present in system with RE.

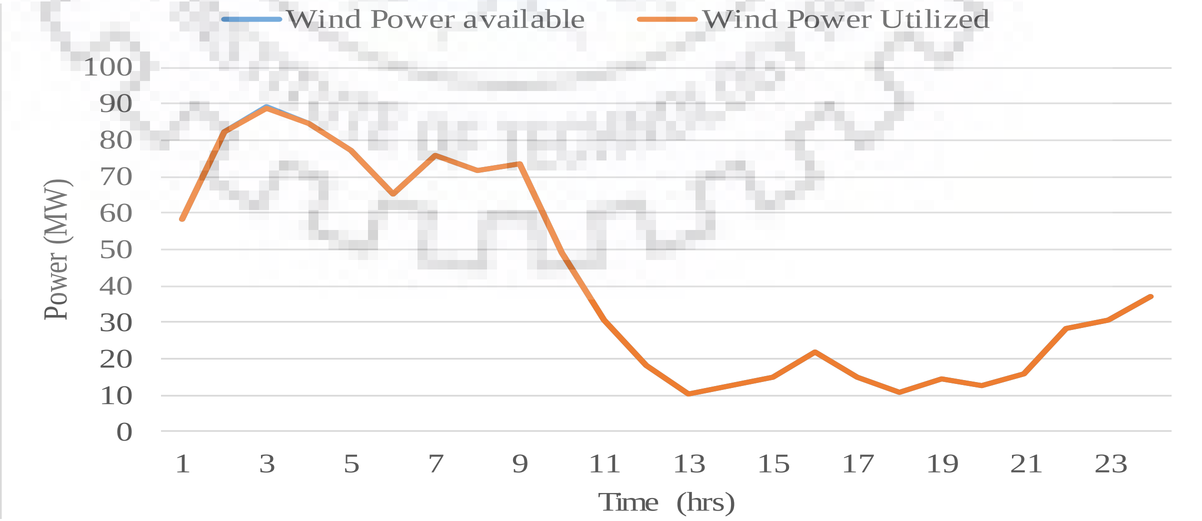

Figure 4.6: Available wind power vs Wind power utilized for case 2

CASE 3: Scheduling Of Thermal, Hydro and Wind System with One PSH Unit and Increased Wind Energy Penetration

In this case penetration of wind power is increased. Everything in this case is same as case 2 and wind power is increased by 40%. In figure 4.7 power scheduling from each generating unit and power used for pumping of PSH unit is shown. Effect of increasing RE penetration can be observed from figure 4.7. In this case, when available wind power is more from 2nd to 10th hour, PSH unit is pumping more power as compare to case 2 also PSH unit generating more power from 17th to 24th hour when wind power is low. Cost of generation from thermal unit in this case is $11630. Cost of thermal power plant reduced by 7.80% compare to case 2. Figure 4.8 shows the comparison between available and utilized wind power of each hour in case 3, from this figure it can be observed that when the available wind power is high comparatively (from 1st to 11th hour) the system is not using all the available wind power and curtailment of wind power is significant in this case. The major reason of curtailment of wind power in slow ramp rate of conventional generator, line congestion and capacity of storage in PSH is low. Curtailment of wind power is not good for economics and environment this should be minimum. In this case, curtailment of wind is 7.98%.

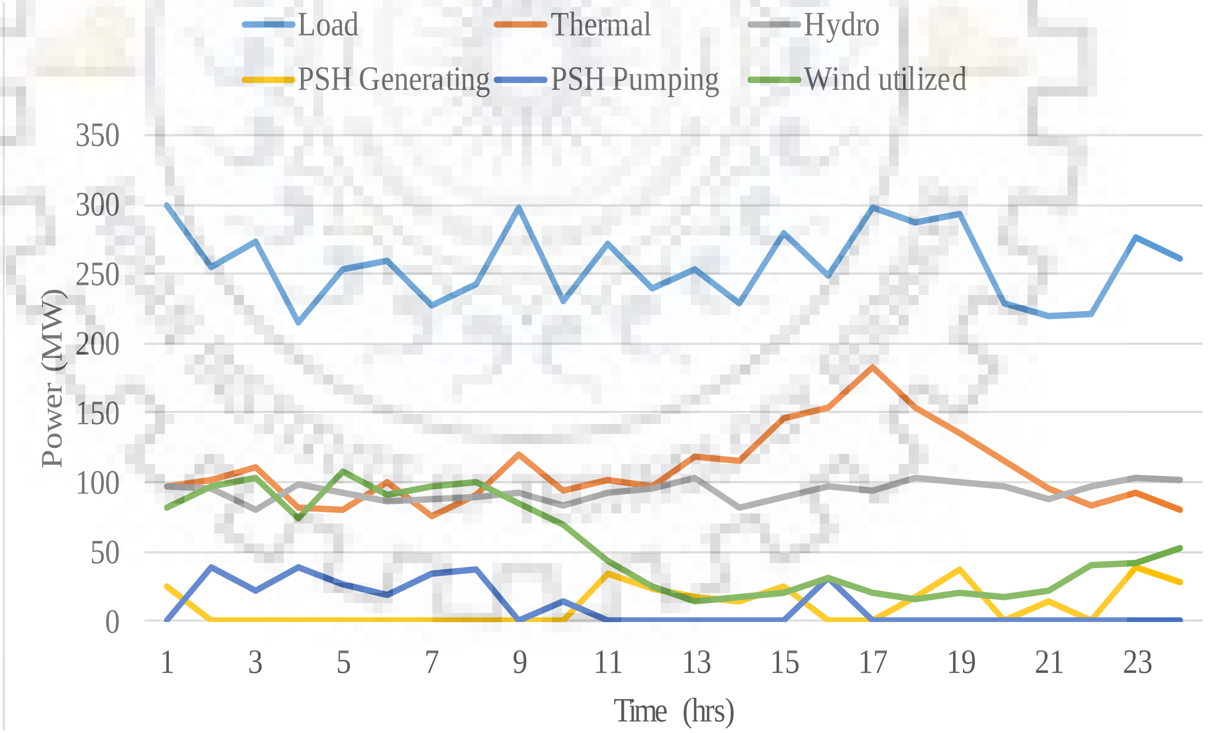

Figure 4.7: Power from each generating unit for case 3

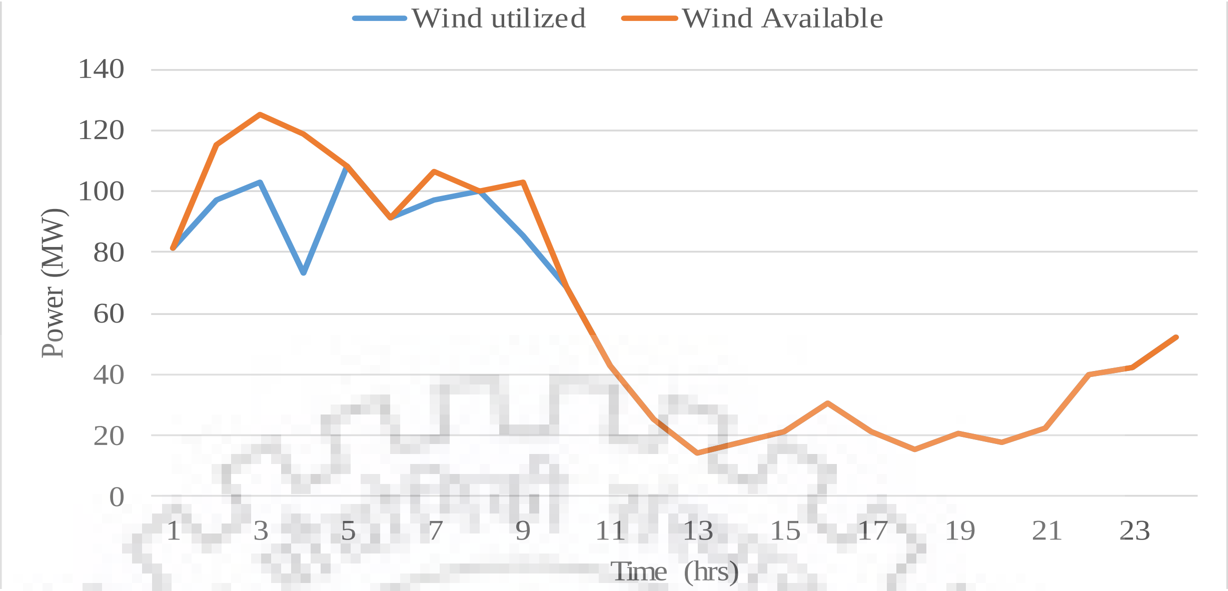

Figure 4.8: Comparison between wind power available and utilized in case 3

CASE 4: Scheduling Of Thermal, Hydro and Wind System with Three PSH Unit and Increased Wind Energy Penetration

In this case with increased penetration level of wind as case 3, 2 more PSH unit have been added to bus 6 (PSH2) and bus 10 (PSH3). Aim of this case to study the effect of adding storage system on curtailment of wind and on the cost of thermal power plant generation. Data related to PSH2 and PSH3 given in table III.

Figure 4.9 shows the power scheduling from thermal unit, hydro unit, wind system, sum of power scheduled from all PSH unit, sum of power used for pumping in all PSH unit and load profile in case 4. Figure 4.9 also shows the PSH is working more in pumping mode when wind power is more and PSH is working is generating mode when wind power is low. Cost of generation from thermal power generator in this case is $11133. In case four, cost of thermal power generating unit is reduced by 11.75% as compared to case 2 and 4.27% as compared to case 3.

Effect of including more storage unit in system can be observe by comparing figure 4.10 and figure 4.8. Figure 4.10 shows the comparison between wind power available and utilized in case 4. Utilized wind power of case 4 increased as compare to case 3 and curtailment of wind reduced significantly in this case. In case 4, wind power curtailment is reduced to 1.2%.

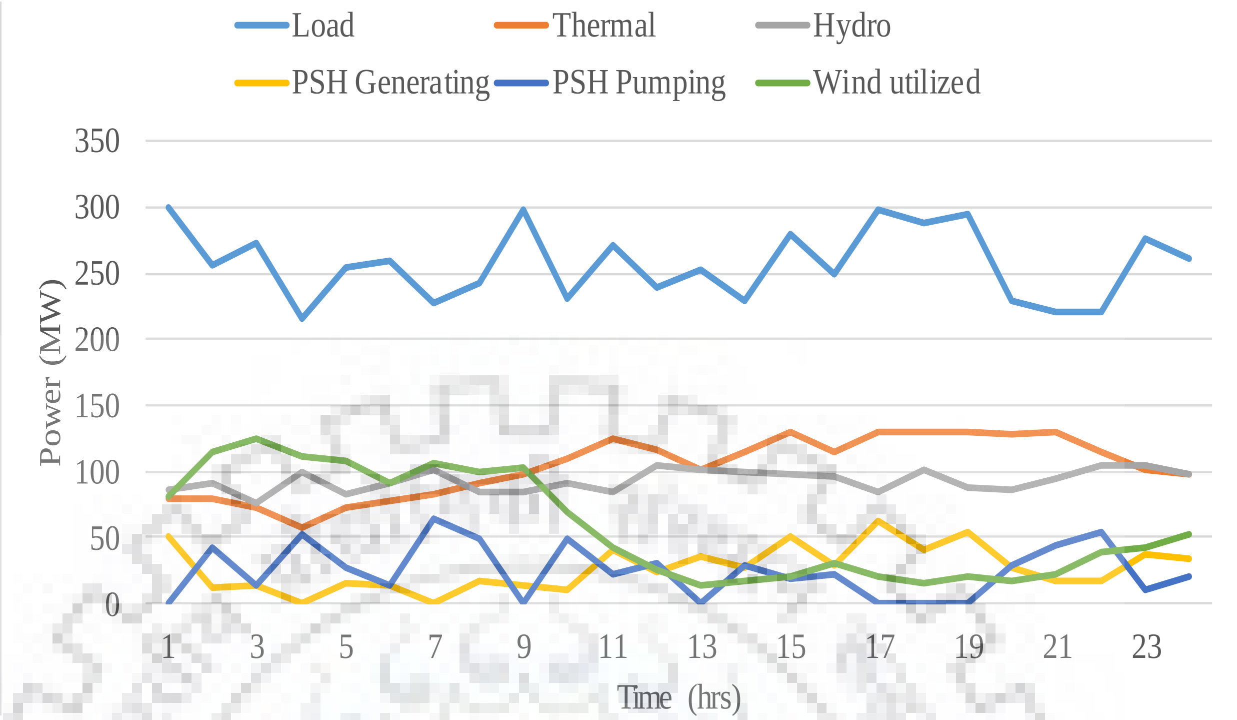

Figure 4.9: Power from each generating unit for case 4

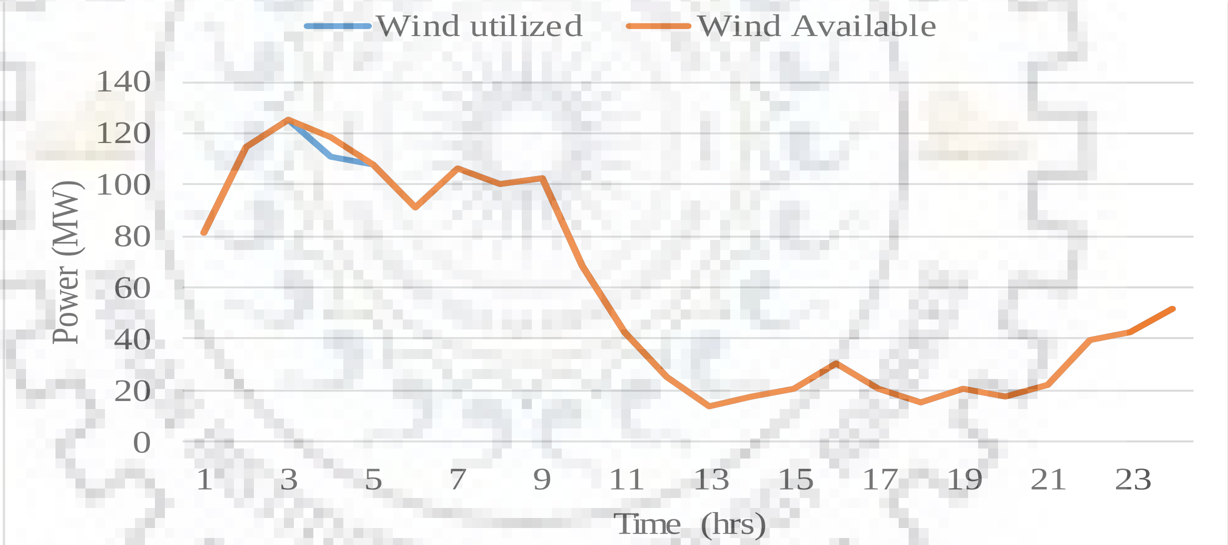

Figure 4.10: Comparison between wind power available and utilized in case 4

4.6 Summary

In this report, power generation cost of thermal power plant is minimized in a 24-hour scheduling with a system having different type of generating unit- hydro power generating unit, Pumped hydro storage unit and Wind energy system. Four case have been studied in this report.

In case 1, the scheduling is done for a system having thermal, hydro and wind energy system without any kind of storage. Result of this case shows curtailment of RE is very high if any storage system is not available and more power is scheduled to thermal power plant.

In Case 2, the scheduling is done for a system having thermal, hydro, PSH unit and wind energy system. In this case, it is shown that PSH unit is working in pumping mode and storing energy when available wind power is high and PSH unit is working in generating mode when available wind power in low. This case concludes that storage unit supports the uncertain nature of availability of RE.

In case 3, Wind energy penetration level is increased and results of this case shows that by increasing penetration of RE in system will result in curtailment of RE. It shows that all the RE cannot be utilized if penetration of RE increases continuously. This case also shows cost of thermal power generation cost reduced with increasing RE penetration.

In case 4, Two more storage unit (PSH) added to the system with increased RE penetration. Result of this case shows, curtailment of RE reduced significantly as compared to case 3 and also cost of thermal power generation is reduced. From this case, it is concluded that with increasing penetration level of RE, storage should be added in system for utilization of more RE and to reduce RE curtailment. Inclusion of storage system with high penetration of RE will reduce generation cost of thermal power and also it will reduce emission of harmful gases from thermal power plant, because power generated from thermal power plant also reduced in this case.

CHAPTER-5

Energy Management with Weather Based DLR, RE Penetration and storage

5.1 INTRODUCTION

In this chapter, impact of weather on transmission lines is discussed. Current capacity of conductor depends on heating of conductor and heating of conductor depends on atmospheric conditions also, so current carrying capacity of conductor varies throughout the day. In power system load scheduling power carrying capacity of lines taken as constant, known as static line rating (SLR). Generally static line rating taken as worst possible rating of line. Line rating which depends on atmospheric conditions and changes continuously is referred as dynamic line rating (DLR). Concept of DLR can help in using line rating very efficiently and it can be a promising solution to problem of line congestion due to high RE penetration in any existing power system network.

A 75-bus [4] existing power system network of Uttar Pradesh and Uttarakhand region of India with all proposed solar power projects in that region has been taken to study the impact of DLR on line congestion and RE penetration. Line data and bus data of this 75-bus system is in Appendix [B]. S_{base} of this system is 100MVA and V_{base} of this system is 400KV. The study has been done with two type of loads, constant load and voltage dependent (ZIP) load model discussed in section (5.3), static and dynamic line rating discussed in section (5.2). Weather based DLR has been calculated for two cases one for summer and another for winter.

5.2 DYNAMIC LINE RATING

Power carrying capacity of transmission lines are defined by thermal and mechanical characteristic of conductor. Maximum allowable sag and allowable thermal heating of overhead transmission line decides its rating. Conventionally power handling capacity of power transmission lines are designed to be static and it termed as static line rating. Line rating depends on many atmospheric conditions. Static line rating is the line rating, assuming worst atmospheric condition. The dynamic line rating changes with temperature, solar radiation and wind speed. For a day ahead scheduling problem dynamic line rating for each hour can be decided with hourly forecasted weather data. Dynamic line rating is decided by ampacity of the conductor. Ampacity is current carrying capacity of conductor at a certain atmospheric condition. Ampacity of conductor is calculated by heat balance equation of conductor at steady state. [6]-[8]

$$Q_J + Q_S + Q_M + Q_I = Q_R + Q_C + Q_W \tag{5.1}$$

Where,

Q_J - Heating by current flowing inside conductor

Q_M - Magnetic heating, which is very small for nonferrous conductor, so it can be neglected

Q_S - Solar heating

Q_I - Heating by corona, that can also be neglected

Q_R - Radiative cooling

Q_C - Convective cooling

Q_W - Evaporative cooling, that can also be neglected.

$$Q_R = \pi D \varepsilon \sigma_e [(T_s + 273)^4 - (T_{amb} + 273)^4] \tag{5.2}$$

σ_e is Stefan-Boltzaman constant

$$\sigma_e = 5.67 \times 10^{-8}\ W/m^2k^4$$

ε is emissivity range (0.23 to 0.95) for new conductor 0.23 and for old conductor 0.95

T_s is surface temperature of conductor

T_{amb} is ambient temperature.

Q_c is convective cooling

$$Q_c = \pi.\lambda.\mathrm{Nu}.(T_s - T_{amb}) \tag{5.3}$$

λ is thermal conductivity

$$\lambda = 0.0243 + T_{amb}.\left\{{(0.0272 - 0.0243)}\Big/{(40 - 0)}\right\} \tag{5.4}$$

Nu is Nusselt number can be calculated as

$$Nu = 0.65Re^{0.2} + 0.23Re^{0.61} \tag{5.5}$$

Re is Reynolds number

$$Re = 1.644\,.\,10^9.VD\left(T_{amb} + 0.5(T_s - T_{amb})\right)^{-1.78} \tag{5.6}$$

Where V is wind velocity and D is diameter of conductor.

Q_s is solar heating

$$Q_s = \propto . S . D \tag{5.7}$$

α is absorptivity, range 0.23 to 0.95, 0.23 for new conductor and 0.95 for old conductor. S is solar radiation and D is diameter of conductor.

$$Q_J = I_{rat}^2 . R \tag{5.8}$$

I_{rat} is ampacity of conductor and R is resistance of conductor.

$$I_{rat} = \sqrt{(Q_R + Q_c - Q_s) / R'_{Tac}} \tag{5.9}$$

$$MVA\ line\ rating = V_{base} * I_{rat} \tag{5.10}$$

5.3 LOAD MODEL

Generally, loads of power system optimization problem taken as constant load known as constant P and constant Q load model. But the actual load of bus is not of a single type they are comprises of many different types of loads like Agriculture, Industrial, Domestic, Commercial etc. and all the loads are not of constant power load. The actual power demanded by the loads depends on impedance current and power characteristic of load and depends on voltage of the node. As the voltage is not constant always in practical scenario so the real power and reactive power demand of load will also vary with the voltage. For the actual representation of load of modern power system a dynamic voltage dependent ZIP load model has been used in this work.

ZIP coefficient model represent a load as polynomial function of operating voltage. It define load as composition of three constant load Z, I and P, where Z stands for constant impedance, I stands for constant current and P stands for constant power load. With Z I and P coefficient and operating voltage active and reactive power demand of load can be determined and it is given by following equations. [9]-[10]

$$P_i = P_0 \left[Z_p \left(\frac{V_i}{V_0} \right)^2 + I_p \left(\frac{V_i}{V_0} \right) + P_p \right] \tag{5.11}$$

$$Q_i = Q_0 \left[Z_q \left(\frac{V_i}{V_0} \right)^2 + I_q \left(\frac{V_i}{V_0} \right) + P_q \right] \tag{5.12}$$

P_0 , Q_0, and V_0 are nominal values of active power, reactive power and voltage respectively. V_i is operating voltage. Z_p, I_p, and P_p are ZIP coefficient for active power and Z_q, I_q, and P_q are ZIP coefficient for reactive power.

$$Z_p + I_p + P_p = 1 \tag{5.13}$$

$$Z_q + I_q + P_q = 1 \tag{5.14}$$

5.4 PROBLEM FORMULATION

In this work, objective problem is to optimization of fuel cost of thermal power generators. Relation of fuel cost and power output of generator is in section (2.5). Problem is defined for two weathers, summer and winter and solved with different cases. A code in MATLAB is developed to solve this optimization problem. Fuel cost of thermal power generator is defined in equation as non-linear function of power output of generator. Cost optimization function is defined in equation (4.1).

$$minimize \left\{ \left(\sum_{i=1}^{t} \sum_{j=1}^{N_t} C_{i,j} \right) + \sum_{k=1}^{N_L} \hat{S}.k1 \right\} \tag{5.15}$$

In objective function of previous problem in section (4.2), $\hat{S}$ and K is not given. For a large system it is not feasible to solve the scheduling problem with strict line limit constraint. To relax the line limit constraint a new variable is introduced in problem $\hat{S}$, which is extra power flowing through a line and this surplus power is added into objective function by multiplying with a constant *k1* as a virtual penalty cost for overloading of line [32]. This will lead to solution with minimum overflow in any line. In this work *k1* is 15. N_L is number of lines in system. To keep voltage close to the nominal voltage defined for the bus, a new objective function is defined here including penalty factor for voltage deviation. This objective function is given in equation (5.16).

$$minimize \left\{ \left(\sum_{i=1}^{t} \sum_{j=1}^{N_t} C_{i,j} \right) + \sum_{k=1}^{N_L} \hat{S}.k1 + \sum_{l=1}^{N_{bus}} \sum_{m=1}^{t} |\Delta V_{i,j}|.k2 \right\} \tag{5.16}$$

Here *k2* is penalty factor introduces for voltage deviation ΔV. N_{bus} is number of buses and *t* is number of hours.

The above mentioned both objective functions have to be minimized for different weather with different cases to get the scheduling results. These objective problems have to be solved to meet all the constraints related to generators. Constraints related to thermal power are in equation

(2.10)-(2.12), constraints related to hydro power are in equation (2.16)-(2.18), constraints related to pumped hydro storage system are in equation (2.20)-(2.24) , constraint related to solar power generations are in equations (2.42) and security constraints described below. Transmission line power flow limit constraint is in equation (5.20) and constraint for voltage deviation is in equation (5.21). In this problem variables are Power to be schedule to thermal power generator for each hour, water discharge rate for hydro and pumped hydro system for each hour, Power to be scheduled to solar power station for each hour, Voltage deviation (ΔV) for each bus for each hour, load angle (θ) of each bus for each hour and surplus power ($\hat{S}$) flowing through the line.

Real and reactive power flowing through a line can be define in the form of nominal voltage of buses (V_{nom}) , voltage deviation (ΔV), load angle (θ), conductance of line (g) and susceptance (b) of the line [33] given in equation (5.17) and (5.18). Conductance and susceptance of line can be determined from line data given in Appendix[B]. V_{nom} is 1 pu for all load buses (bus 16 to 75) and V_{nom} for generator buses (bus 1 to 15) are given in Appendix [B]. ΔV and θ are variable here.

$$P_k^t = V_{nom}\left(\Delta V_i^t - \Delta V_j^t\right)g_k - V_{nom}^2 b_k\left(\theta_i^t - \theta_j^t\right) \tag{5.17}$$

$$Q_k^t = -V_{nom}\left(\Delta V_i^t - \Delta V_j^t\right)b_k - V_{nom}^2 g_k\left(\theta_i^t - \theta_j^t\right) \tag{5.18}$$

P_k^t and Q_k^t are active and reactive power respectively flowing in k^{th} line connected between i^{th} and j^{th} bus at time t. Apparent power (MVA) flowing in k^{th} line at time t can obtained from equation (5.19).

$$S_k^t = \sqrt{(P_k^t)^2 + (Q_k^t)^2} \tag{5.19}$$

Power (MVA) flowing in a k^{th} line at time t should be less than the rating of the line (L_k^t). To relax this constraint in this optimization problem a surplus power ($\hat{S}$) introduced above. Therefore, Constraint for power flowing in a line is is defined as equation (5.20)-

$$|S_k^t| \leq L_k^t + \hat{S}_k \tag{5.20}$$

Constraint for voltage deviation

$$-0.10 \leq \Delta V \leq 0.10 \tag{5.21}$$

Real and reactive power scheduled to generators should meet the real and reactive power demand. This constraint is given in equation (5.22) and (5.23)-

$$\sum_{i=1}^{N_t} P\_th_i^t + \sum_{i=1}^{N_{hyd}} P\_hyd_i^t + \sum_{i=1}^{N_{psh}} P\_psh\_g_i^t - \sum_{i=1}^{N_{psh}} P\_psh\_p_i^t + \sum_{i=1}^{N_{pv}} P\_pv_i^t = \sum_{i=1}^{N_{bus}} P\_load_i^t \quad ; for\ t = 1,2 \ldots 24 \tag{5.22}$$

$$\sum_{i=1}^{N_t} Q\_th_i^t + \sum_{i=1}^{N_{hyd}} Q\_hyd_i^t + \sum_{i=1}^{N_{psh}} Q\_psh\_g_i^t = \sum_{i=1}^{N_{bus}} Q\_load_i^t \,; for\ t = 1,2 \ldots..24 \tag{5.23}$$

Equation (5.22) is constraint for active power load balance and equation (5.23) is constraint for reactive power balance at a time *t*. Here *P_th*, *P_hyd*, *P_psh_g* and *P_pv* are active power scheduled to Thermal power plant, Hydro generator, PSH in generating mode and solar energy system respectively *Q_th*, *Q_hyd* and *Q_psh_g* are reactive power scheduled to thermal, hydro and pumped hydro generator respectively. N_t, N_{hyd}, N_{psh} and N_{pv} are number of Thermal generator, hydro generator, PSH unit and wind energy system. *P_psh_p* is power used by PSH in pumping mode at time *t*. *P_load* is load at i^{th} bus at time *t* and N_{bus} number of buses is system.

5.5 SOLUTION STRATEGY (NONLINEAR OPTIMIZATION)

The objective of this work is to minimize the total cost of load scheduling, considering all the constraints. In large power system generation cost of generators and mostly constraints related to power system are non-linear. It is not possible to linearize all the constraints. There is an optimization function available in MATLAB software to solve nonlinear minimization problem named "*fmincon*" [29]. Structure of this function with *n* different variable is given below.

Objective function-

$$Minimize\,\{f\,(x_1, x_2 \ldots\ldots\ldots.x_n)\} \tag{5.24}$$

$f(x_1, x_2, \ldots\ldots x_n)$ is non-linear function of variable *x*. In MATLAB non-linear objective is provided in the form of function, which returns a symbolic equation function of *x* to main function to operate with *fmincon*. Subject to constraints-

$$A.x \le b \tag{5.25}$$

$$A_{eq}.x = b_{eq} \tag{5.26}$$

Equation (5.25) and (5.26) are linear non-equality and equality constraint respectively. *A* and A_{eq} are vector of size 1×n for each constraint. *x* is variable vector of size n×1. *b* and b_{eq} are vector of size n×1.

$$c(x) \leq 0 \tag{5.27}$$

$$c_{eq}(x) = 0 \tag{5.28}$$

Equation (5.27) and (5.28) are non-linear inequality and equality constraint. In MATLAB these non-linear constraints are provided in the form of a function, which return a symbolic non-linear constraint function of variable *x*.

$$lb \leq x \leq ub \tag{5.29}$$

lb and *ub* represents lower bound and upper bound of variable *x*. These are vector of size of variable.

A script is required in MATLAB for optimization which generates all the required matrices and functions mentioned above from the original problem for optimization then the below mentioned command can be used to minimize the objective function.

$$x = fmincon\big(fun, x0, A, b, A_{eq}, b_{eq}, lb, ub, nonlcon\big); \tag{5.30}$$

This command will give the final value of variable *x* after minimizing the objective function and satisfying all the linear, non-linear, lower bound and upper bound constrains. *fun* represents non-linear objective function and *nonlcon* represents non-linear constraints which obtained from objective function and non-linear function script. Here *x0* is initial guess value of variables and it can be set equal to lower bound of variable.

5.6 TEST SYSTEM

A 75-bus transmission power system of Uttar Pradesh and Uttarakhand region of India is considered here for study. This system has 15 generator buses connected with 12 thermal, 2 hydro and 1 pumped hydro storage type units. Bus 1 to 4 and bus 8-15 are connected with thermal power generators in which generators connected to bus 12-15 run with a fixed power generation. Bus 5 and bus 6 are connected with hydro power generators. Bus 7 is connected with pumped storage hydro unit. These all generators are of the same capacity as mentioned in bus data of 75-bus system. Apart from this, 10 proposed solar-based power projects by Department of additional source of energy, Government of Uttar Pradesh is also considered here based on their proposed location and capacity mentioned in [30]. Each proposed solar power generating station is connected to the bus nearest to their proposed location. 10 solar power generating stations are connected to bus 19, 26, 35, 41, 42, 45, 47, 50, 69 and 70. Load of each load bus from bus number 16 to 75 is given in bus data of the system in Appendix [B]. To generate 24 hours load profile, given load is varied from 80% to 120% with the help of MATLAB random number generator. Sum of real and reactive power demand of all buses is in figure (5.1) and figure (5.2) respectively.

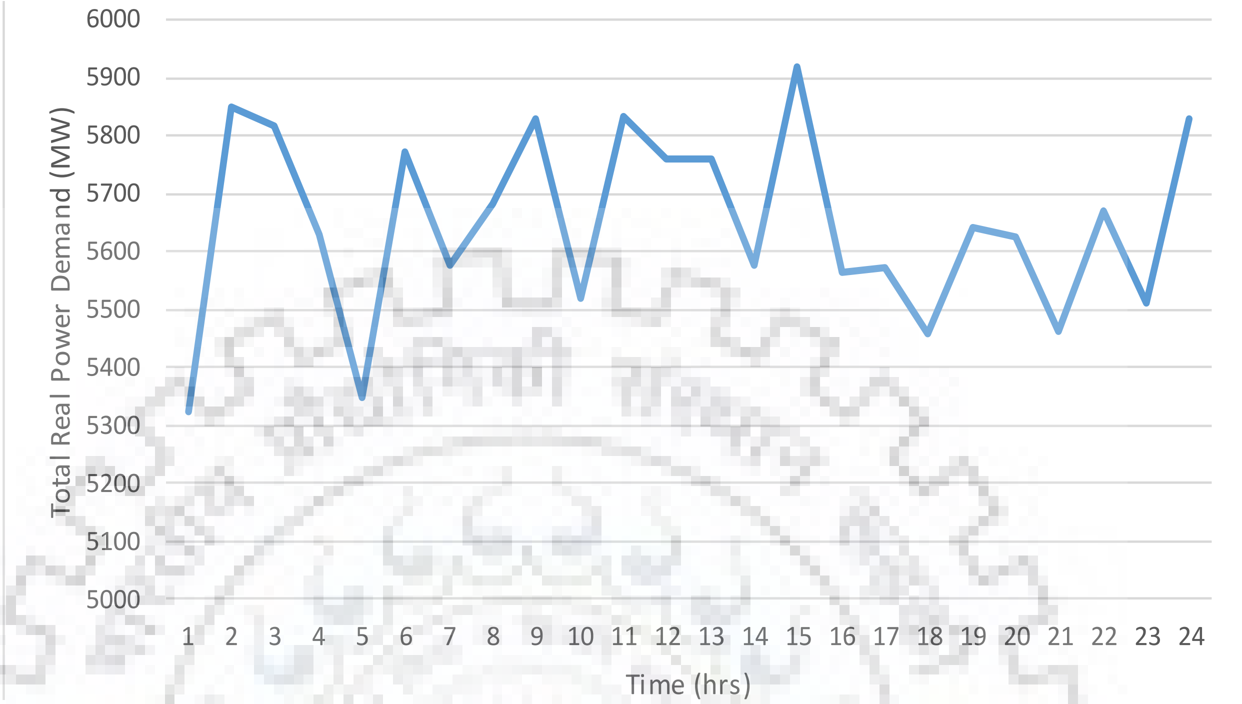

Figure 5.1: Total real power demand for 75-bus system

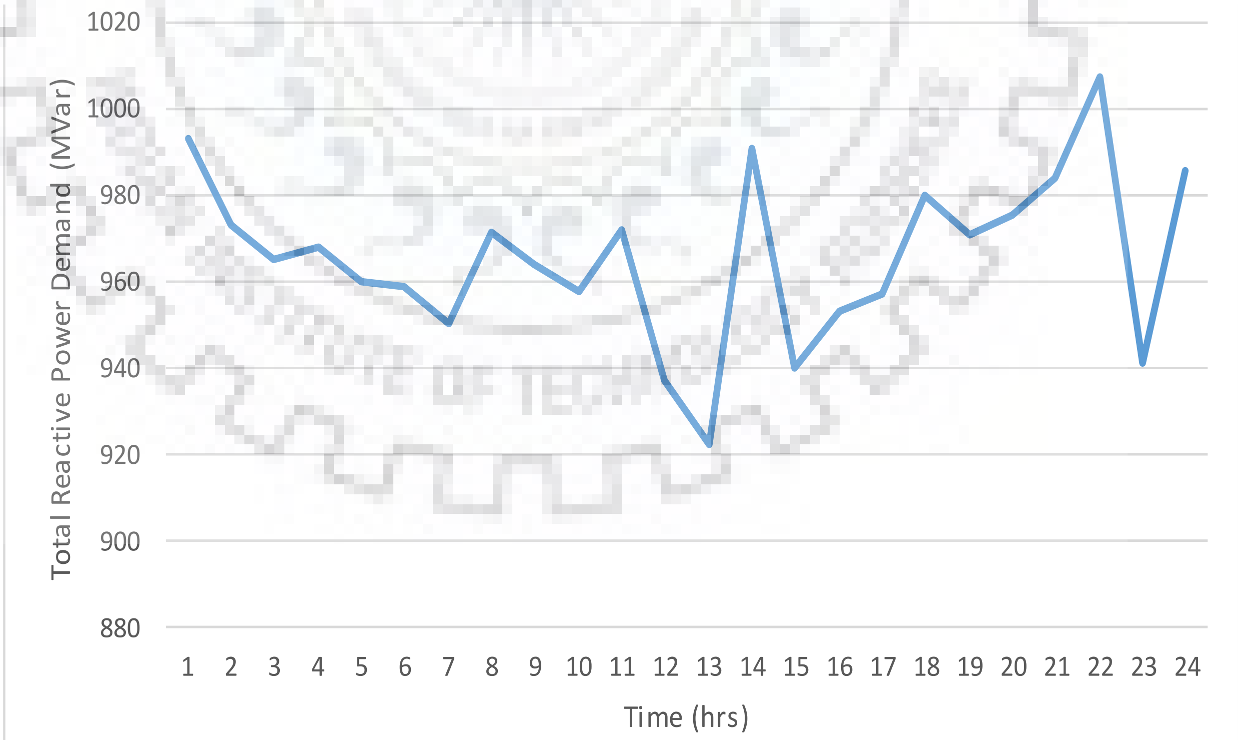

Figure 5.2: Total reactive power demand for 75-bus system

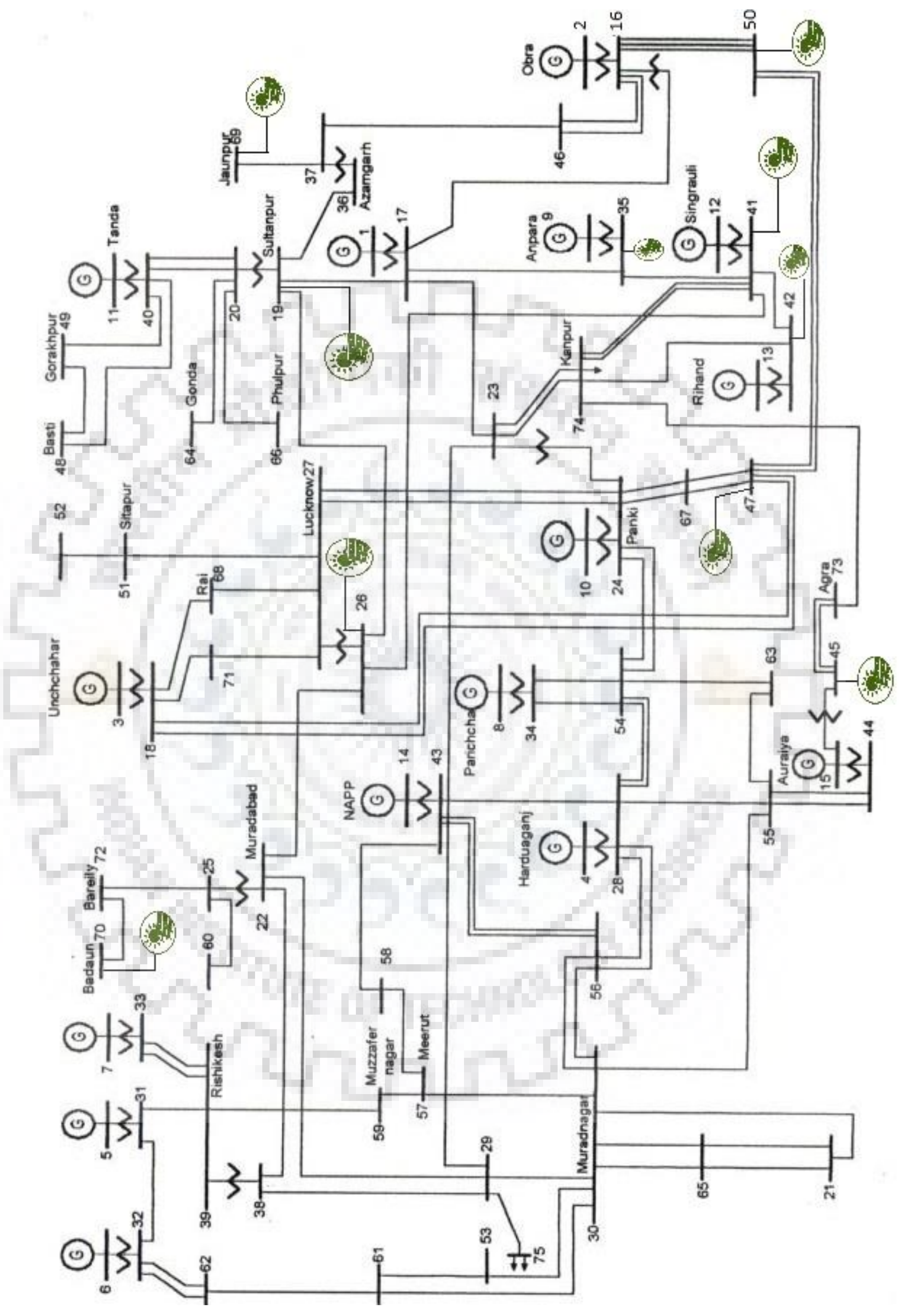

Figure 5.3: Uttar Pradesh (India) 75-bus system with proposed PV generation

Data related to all generating station is collected from many sources. Thermal generating station cost characteristic data is taken from [17] and it is shown in table V. Data related to hydropower generating station and data of reservoir is taken from [22] and it is mentioned in table VI. Pumped storage hydro generating station data is taken from [13] and it is mention in table VII.

Table V: Thermal power generating unit data for 75-bus system

Generator	*Bus*	*a*	*B*	*c*	P_{min} *(MW)*	P_{max} *(MW)*	*Ramp up Rate (MW/hr)*	*Ramp down rate (MW/hr)*
1	1	0.005	2.45	105	100	900	150	150
2	2	0.005	3.51	88.1	100	300	80	80
3	3	0.0041	2.6	92	40	200	50	50
4	4	0.0052	8.3	78	40	170	50	50
5	8	0.0042	6.22	83	60	570	100	100
6	9	0.0055	3.21	82	20	100	25	25
7	10	0.0056	2.86	98	30	120	30	30
8	11	0.0048	3.28	82	40	200	50	50

a, b and c are cost characteristic coefficient of thermal power generators. Cost characteristic of thermal power generator is in section (2.5). P_{min} and P_{max} are minimum and maximum generating capacity of thermal generator. Ramp up and ramp down rate is also in table V. In table V data of only 8 thermal generators is given rest of 4 generators always runs on a fixed power output so cost related data of that generators are not required in this analysis.

Table VI: Hydro generating unit data for 75-bus system

Unit	*Bus*	*F1(Mw/ m³/sec)*	*F2(Mw/ m³/sec)*	*F3(Mw/ m³/sec)*	Q_{min} *(m³/sec)*	Q_{max} *(m³/sec)*	V_{min} *(Hm³)*	V_{max} *(Hm³)*	V_0 *(Hm³)*	V_f *(Hm³)*	W_i *(Hm³/hour)*
1	5	0.9	1.1	1.2	0	180	82	133	96	96	0.59
2	6	1.8	1.6	1.9	0	70	121	256	217	217	0.18

In table VI data related to two hydro power generators are given which are connected to bus 5 and bus 6. *F1, F2* and *F3* are piecewise multiplying factor which converts water discharge rate to power generated by generators as discussed in section (2.6). Q_{min} and Q_{max} are minimum and maximum allowable water discharge rate. V_{min}, V_{max}, V_o, and V_f, are minimum, maximum, initial and final volume of water of reservoir. W_i is nature water inflow rate into reservoir.

Table VII: Pumped hydro storage unit data for 75-bus system

Unit	*Bus*	V_{max} (Hm^3)	V_{min} (Hm^3)	V_i (Hm^3)	V_f (Hm^3)	Q_{min} (hm^3/hr)	Q_{max} (hm^3/hr)	α'	β'	γ'
1	7	150	50	55	55	5	15	-0.033	2.5	0

Data of one pumped storage hydro unit which is connected to bus 7 is in table VII. Here α', β' and γ' are coefficient which of power generation equation of pumped storage hydro unit as discussed in section (2.6). Q_{min} and Q_{max} are minimum and maximum possible discharge rate of water V_{max}, V_{min}, V_i, and V_f are maximum, minimum, initial and final volume of reservoir.

Forecasted data for solar radiation is taken form a report [25] of Varanasi for summer and winter season. Sun radiation data of Varanasi is varied randomly 80% to 120% with MATALB random number generator. Solar power generator output is calculated by method discussed in section (2.9). Rating of all 10 solar power station is given in table VIII. Solar radiation for both season of solar generator 1 and power output is in figure (5.4) and figure (5.5) respectively. Rating of all PV generators are taken from [30], which are proposed to be installed at that location.

Table VIII: Rated power of solar power station

PV generator	1	2	3	4	5	6	7	8	9	10
Bus	19	26	35	41	42	45	47	50	69	70
Rated Power (MW)	130	20	20	65	200	5	20	70	75	40

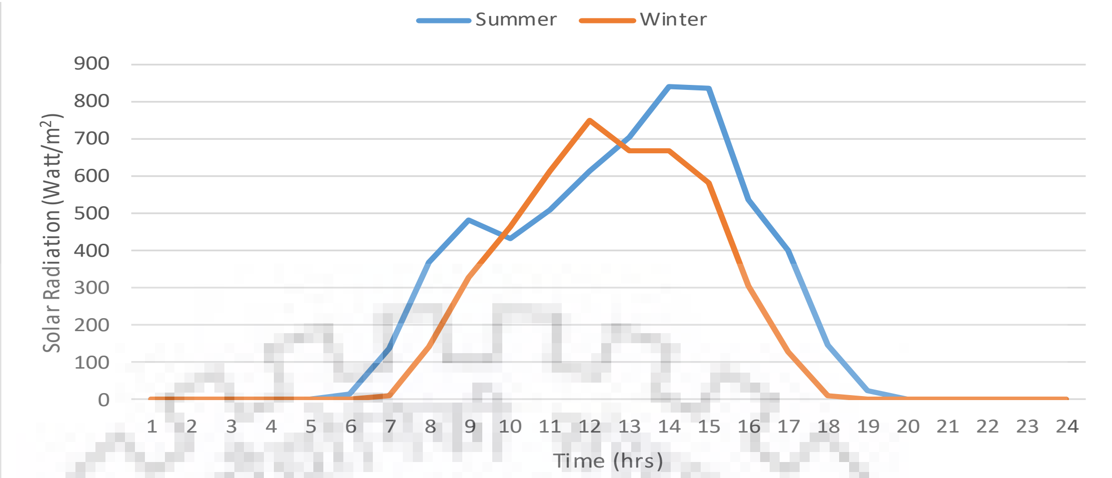

Figure 5.4: Solar radiation in at solar power plant 1 for summer and winter

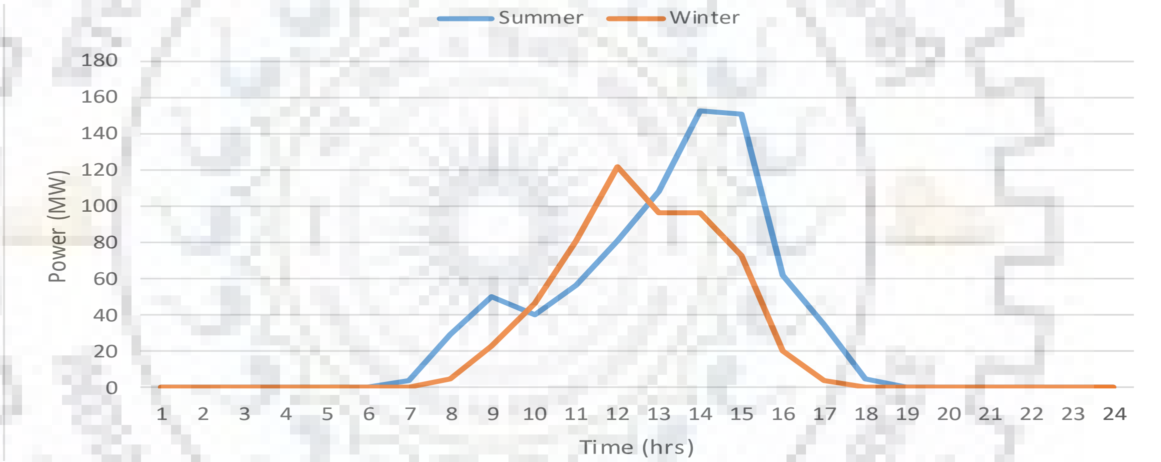

Figure 5.5: Solar power generated by solar plant 1

5.7 DYNAMIC LINE RATING CALCULATION

Concept and calculation method of DLR is in section (5.2). For the calculation of DLR weather related data and data related to conductor used in transmission line is required. Data related to conductor diameter of conductor, resistance and maximum surface temperature of conductor taken from website of Uttar Pradesh Power Transmission Corporation Limited [23]. It is mentioned on this website in Uttar Pradesh transmission system voltage level 400KV Twin moose ACSR conductor is used which have resistance of 2.921 ohm/km, effective diameter of 31.77mm and maximum surface temperature (T_S) 80^0C. Emissivity (ε) and Absorptivity (α) of conductor vary from 0.23 to 0.95, for new conductor it is 0.23 and for old is is 0.95. In this work Emissivity and Absorptivity is considered 0.70 and 0.65 respectively [7]. In this work line rating is calculated for four different periods of the day, the whole day is categorized is four sections early morning, noon, evening and late night. Average wind speed and temperature for all the lines of 75-bus system is taken from a weather forecasting website [24] for two different days one for winter and one for summer has been taken. Solar radiation of Varanasi, Uttar Pradesh is taken from [25] and randomly varied with the help of MATLAB random number generator from 80% to 120% for all the lines. Ambient temperature and wind speed for each period and for each line is given in Appendix [C]. Variation of line rating calculated for summer and winter of line number 16 is shown is figure(5.6).

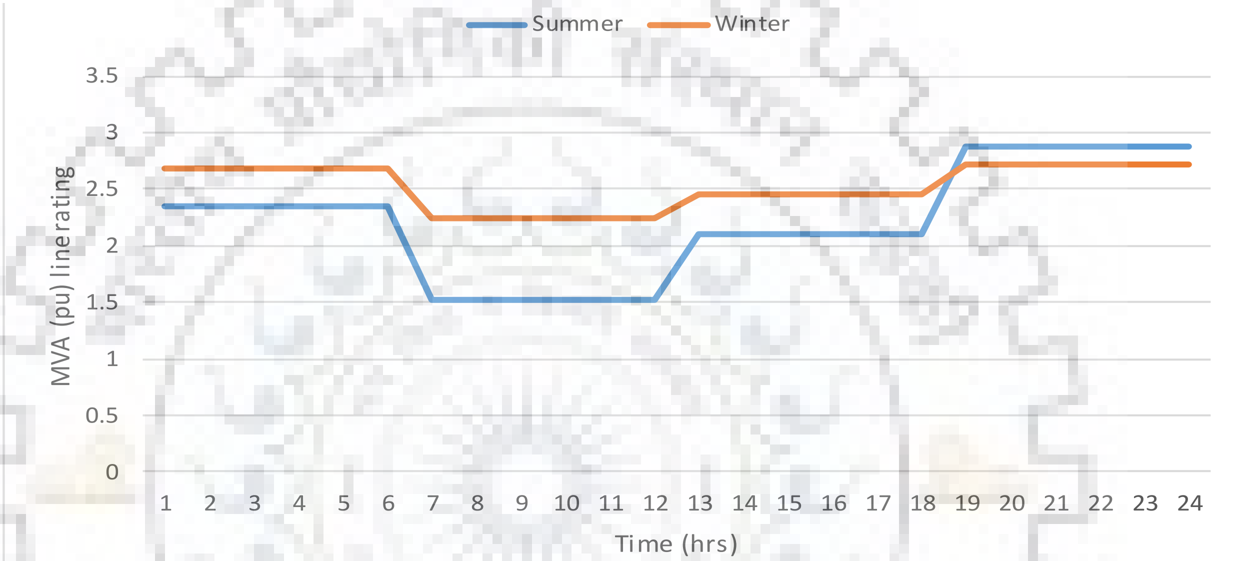

Figure 5.6: Dynamic line rating for summer and winter of line 16

5.8 ZIP Coefficient Estimation

The concept of dynamic load model is discussed in section (5.3). For ZIP model of load Z I and P Coefficient of load at each bus is required. For determination of Z I and P coefficients load of each bus categorized in four sections industrial, commercial, residential and agriculture. The percentage load sharing in all four categories of Uttar Pradesh in given in a joint report of government of Uttar Pradesh and government of India “24×7 Power for all Uttar Pradesh” [26]. Based on geographical location of all buses of UP 75-bus system mentioned in [27], some random research on type of loads of that location and overall UP load categories the percentage load sharing of each bus is decided. The load sharing of all buses is given in Appendix [D].

Z I and P coefficient of each category of load is calculated in [28] by categorizing load on basis of their characteristic. Z I and P coefficient category wise of load given below in table IX.

Table IX: ZIP coefficient of different type of loads

	Z_p	I_p	P_p		Z_q	I_q	P_q
Industrial	0	0.08	0.92		1.97	-2.53	1.56
Commercial	0.28	0.02	0.7		1.58	-1.98	1.4
Residential	0.38	-0.02	0.64		1.29	-0.84	0.55
Agriculture	0.46	0.11	0.43		1.55	-1.7	1.15

ZIP coefficient of each load bus is calculated by Z I and P coefficient of each category of load given in table IX and percentage of type of load at that bus given in Appendix [D] with the equations (5.1-5.6) [28] given below.

$$Z_p^i = \frac{1}{100}\{(L_I^i.Z_p^I) + (L_C^i.Z_p^C) + (L_R^i.Z_p^R) + (L_A^i.Z_p^A)\} \tag{5.31}$$

$$I_p^i = \frac{1}{100}\{(L_I^i.I_p^I) + (L_C^i.I_p^C) + (L_R^i.I_p^R) + (L_A^i.I_p^A)\} \tag{5.32}$$

$$P_p^i = \frac{1}{100}\{(L_I^i.P_p^I) + (L_C^i.P_p^C) + (L_R^i.P_p^R) + (L_A^i.P_p^A)\} \tag{5.33}$$

$$Z_q^i = \frac{1}{100}\{(L_I^i.Z_q^I) + (L_C^i.Z_q^C) + (L_R^i.Z_q^R) + (L_A^i.Z_q^A)\} \tag{5.34}$$

$$I_q^i = \frac{1}{100}\{(L_I^i.I_q^I) + (L_C^i.I_q^C) + (L_R^i.I_q^R) + (L_A^i.I_q^A)\} \tag{5.35}$$

$$P_q^i = \frac{1}{100}\{(L_I^i.P_q^I) + (L_C^i.P_q^C) + (L_R^i.P_q^R) + (L_A^i.P_q^A)\} \tag{5.36}$$

Z_p^i , I_p^i and P_p^i are Z I and P coefficients for estimation of real power demand at i^{th} bus and Z_q^i , I_q^i and P_q^i are Z I and P coefficients for estimation of reactive power demand at i^{th} bus. L_I^i, L_C^i, L_R^i, and L_A^i are load percentage sharing of industrial, commercial, residential and agriculture load respectively at i^{th} bus. ZIP coefficient calculated with this procedure for all load buses are given in table X.

Table X: ZIP Coefficient of load bus

Bus number	Z_p	I_p	P_p	Z_q	I_q	P_q
16	0.366	0.0235	0.6105	1.4325	-1.3105	0.878
17	0.334	0.0175	0.6485	1.455	-1.366	0.911
18	0.347	0.0285	0.6245	1.4665	-1.395	0.9285
19	0.362	0.017	0.621	1.4195	-1.2675	0.848
20	0.366	0.0235	0.6105	1.4325	-1.3105	0.878
21	0.271	0.043	0.686	1.599	-1.7765	1.1775
22	0.248	0.0415	0.7105	1.62	-1.818	1.198

23	0.281	0.039	0.68	1.57	-1.6625	1.0925
24	0.216	0.041	0.743	1.646	-1.83	1.184
25	0.248	0.0415	0.7105	1.62	-1.818	1.198
26	0.371	0.0215	0.6075	1.418	-1.2535	0.8355
27	0.268	0.0225	0.7095	1.555	-1.677	1.122
28	0.3622	0.0131	0.6247	1.4126	-1.2649	0.8523
29	0.3064	0.0282	0.6654	1.5076	-1.4696	0.962
30	0.316	0.014	0.67	1.4615	-1.3505	0.889
31	0.254	0.031	0.715	1.578	-1.661	1.083
32	0.254	0.031	0.715	1.578	-1.661	1.083
33	0.34	0.007	0.653	1.413	-1.209	0.796
34	0.372	0.013	0.615	1.3905	-1.1535	0.763
35	0.3704	0.0104	0.6192	1.3853	-1.1363	0.751
36	0.3392	0.0116	0.6492	1.4336	-1.3064	0.8728
37	0.3264	0.0114	0.6622	1.444	-1.3112	0.8672
38	0.3188	0.0134	0.6678	1.4576	-1.345	0.8874
39	0.3188	0.0134	0.6678	1.4576	-1.345	0.8874
40	0.358	0.0105	0.6315	1.4065	-1.2245	0.818
41	0.3392	0.0116	0.6492	1.4336	-1.3064	0.8728
42	0.3608	0.0099	0.6293	1.4026	-1.219	0.8164
43	0.3516	0.0115	0.6369	1.4124	-1.2182	0.8058
44	0.3556	0.0088	0.6356	1.4001	-1.1813	0.7812
45	0.3372	0.0076	0.6552	1.4169	-1.2145	0.7976
46	0.3496	0.0123	0.6381	1.4182	-1.241	0.8228
47	0.337	0.0071	0.6559	1.421	-1.2519	0.8309
48	0.3342	0.0066	0.6592	1.4242	-1.2661	0.8419
49	0.3296	0.0041	0.6663	1.427	-1.2918	0.8648
50	0.3398	0.0157	0.6445	1.4424	-1.3263	0.8839
51	0.3548	0.0064	0.6388	1.3968	-1.1814	0.7846
52	0.363	0.0085	0.6285	1.392	-1.1675	0.7755
53	0.3572	0.0206	0.6222	1.4306	-1.2784	0.8478
54	0.372	0.013	0.615	1.3905	-1.1535	0.763
55	0.36	0.0211	0.6189	1.4274	-1.2642	0.8368
56	0.325	0.0185	0.6565	1.46	-1.3365	0.8765
57	0.259	0.0235	0.7175	1.56	-1.6475	1.0875
58	0.321	0.012	0.667	1.447	-1.2935	0.8465
59	0.315	0.0225	0.6625	1.489	-1.4505	0.9615
60	0.3388	0.0194	0.6418	1.4474	-1.3116	0.8642
61	0.3654	0.0227	0.6119	1.4258	-1.2645	0.8387
62	0.355	0.015	0.63	1.4173	-1.2326	0.8153
63	0.3396	0.0104	0.65	1.424	-1.249	0.825
64	0.335	0.009	0.656	1.4275	-1.266	0.8385
65	0.3222	0.0169	0.6609	1.4625	-1.3594	0.8969
66	0.363	0.0085	0.6285	1.392	-1.1675	0.7755
67	0.3104	0.0163	0.6733	1.47	-1.3528	0.8828

68	0.3556	0.018	0.6264	1.4254	-1.2612	0.8358
69	0.3542	0.0126	0.6332	1.414	-1.2327	0.8187
70	0.3402	0.0134	0.6464	1.4321	-1.2776	0.8455
71	0.3666	0.0103	0.6231	1.3914	-1.1619	0.7705
72	0.3204	0.0057	0.6739	1.4368	-1.291	0.8542
73	0.2862	0.0136	0.7002	1.4973	-1.4518	0.9545
74	0.271	0.0187	0.7103	1.5252	-1.5107	0.9855
75	0.3348	0.0129	0.6523	1.4344	-1.2686	0.8342

5.9 SIMULATED CASE STUDY

The problem defined in previous section with all the constrained solved for two weather. For both weather it has been solved with different cases of static line rating, dynamic line rating, and static load, voltage dependent ZIP load model, without penalty factor for voltage deviation and with different penalty factor on voltage deviation. Following cases for both the weather has be solved.

- Case 1: Static line rating and constant load with objective function equation (5.15).
- Case 2: Dynamic line rating and constant load with objective function equation (5.15).
- Case 3: Dynamic line rating and voltage dependent load model with objective function equation (5.15).
- Case 4: Dynamic line rating, voltage dependent load model and penalty factor on voltage deviation with objective function equation (5.16).

CASE 1 : In this case minimization of objective function 1 equation (5.15) has been done for summer and winter season considering static line rating and constant load. Static line rating is worst possible line rating for the day as discussed in section (5.2).

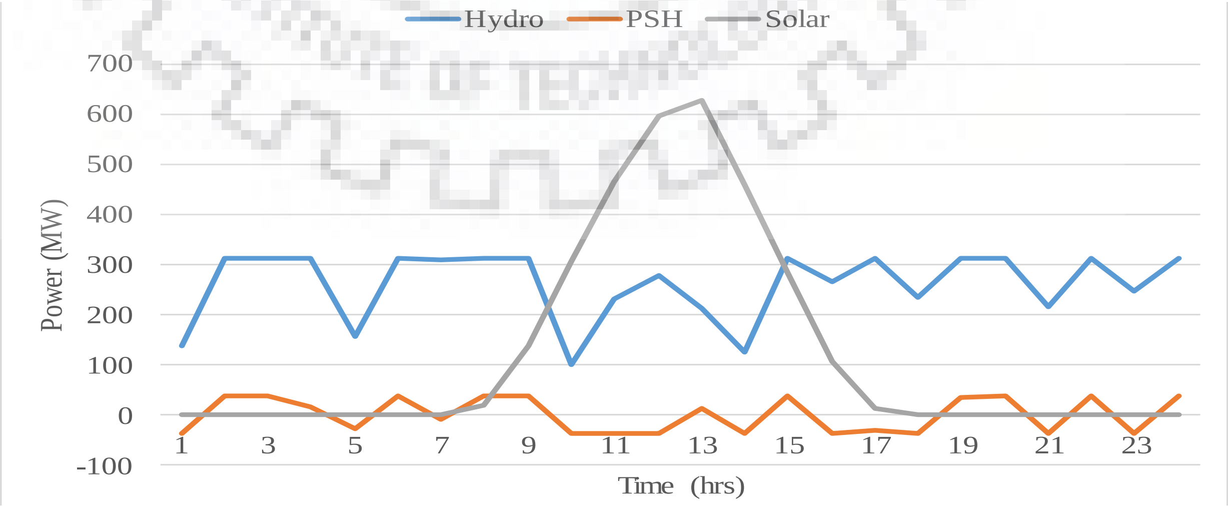

Figure 5.7: Power scheduled to Hydro, PSH and solar plant in case 1 for winter

Power scheduled to hydro, pumped hydro and solar generating stations is shown in figure (5.7) and (5.8). Negative value of pumped hydro scheduled power indicates that it is working in pumping mode.

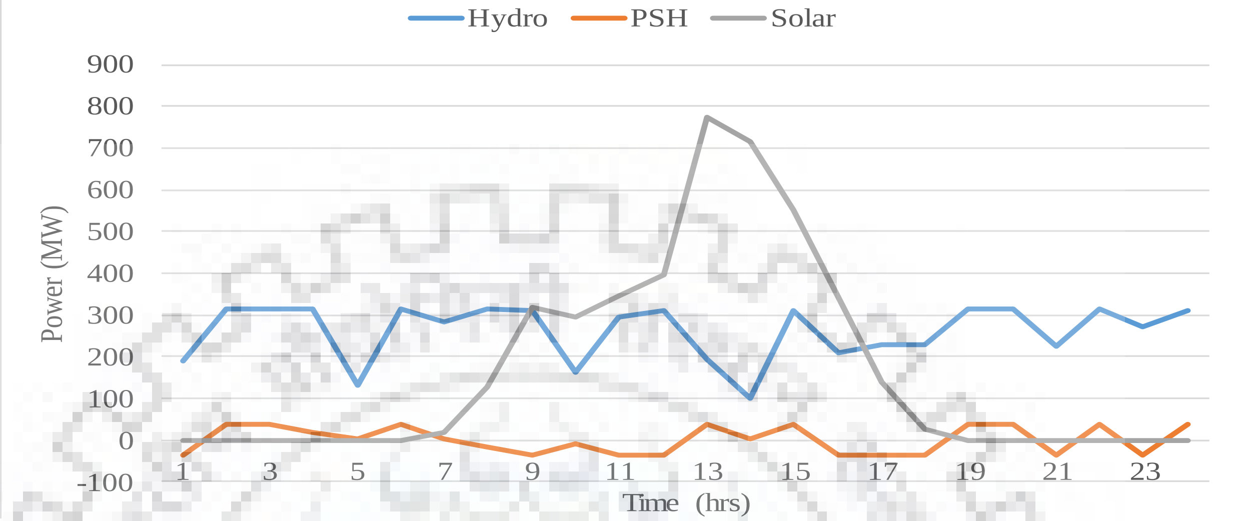

Figure 5.8: Power scheduled to Hydro, PSH and solar plant in case 1 for summer

Due to availability of more solar energy in summer and congestion in line, 2.045% curtailment of solar energy found in this case for summer. In winter, there is not any curtailment of solar energy. Voltage at bus number 46 showing highest voltage fluctuation shown in figure (5.9) for both seasons.

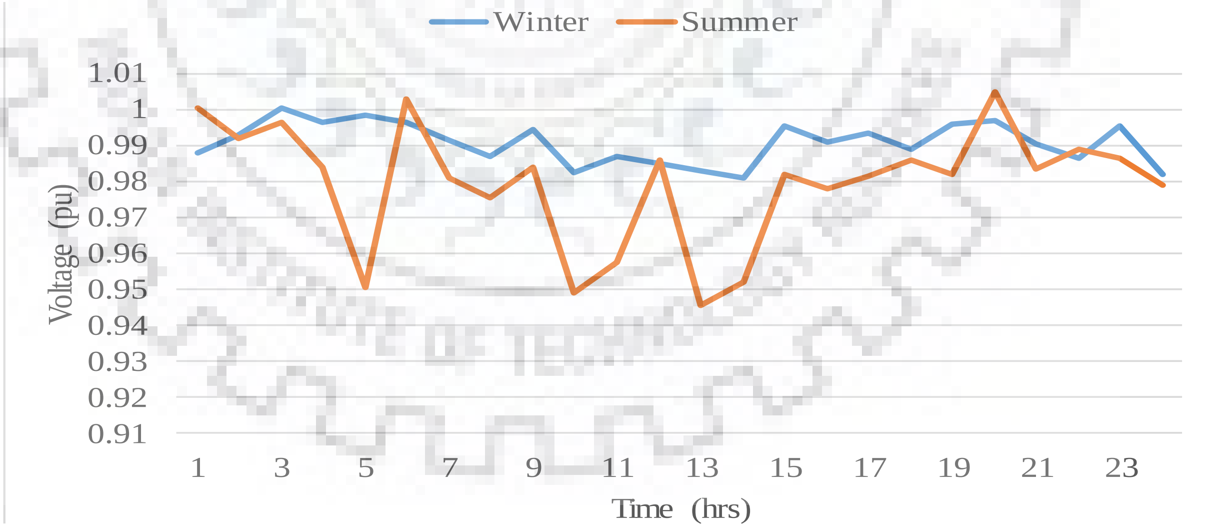

Figure 5.9: Voltage of bus 46 in case 1

CASE 2 : In this section optimization is done for objective function in equation (5.15). Dynamic line rating given in section (5.7) has been considered for both weather in this case. Power scheduled for hydro, pumped hydro and solar generators is shown in figure (5.10) and (5.11).

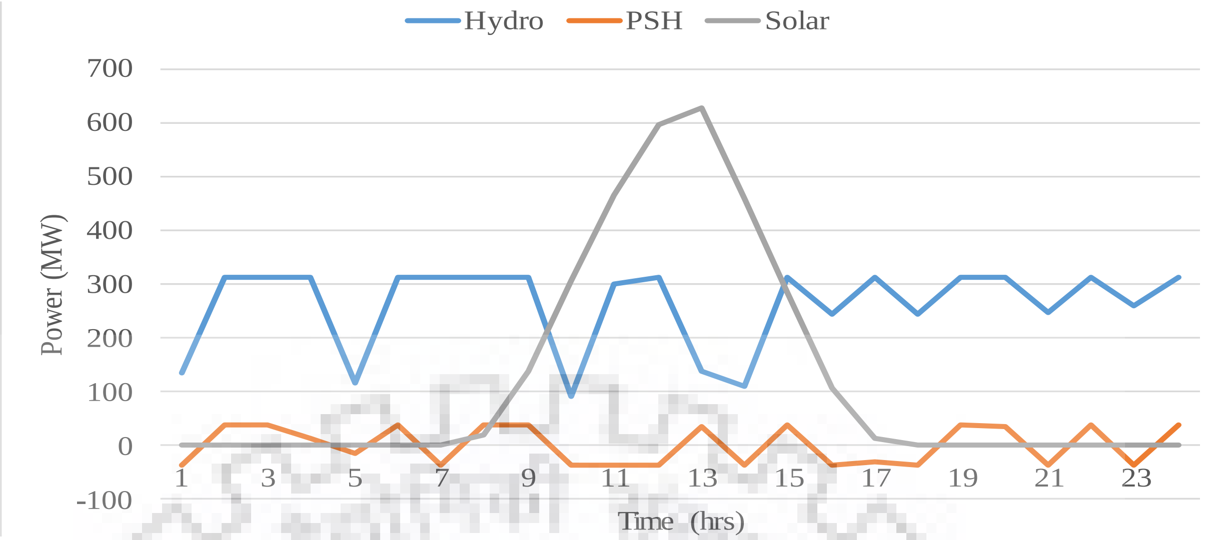

Figure 5.10: Power scheduled to Hydro, PSH and solar plant in case 2 for winter

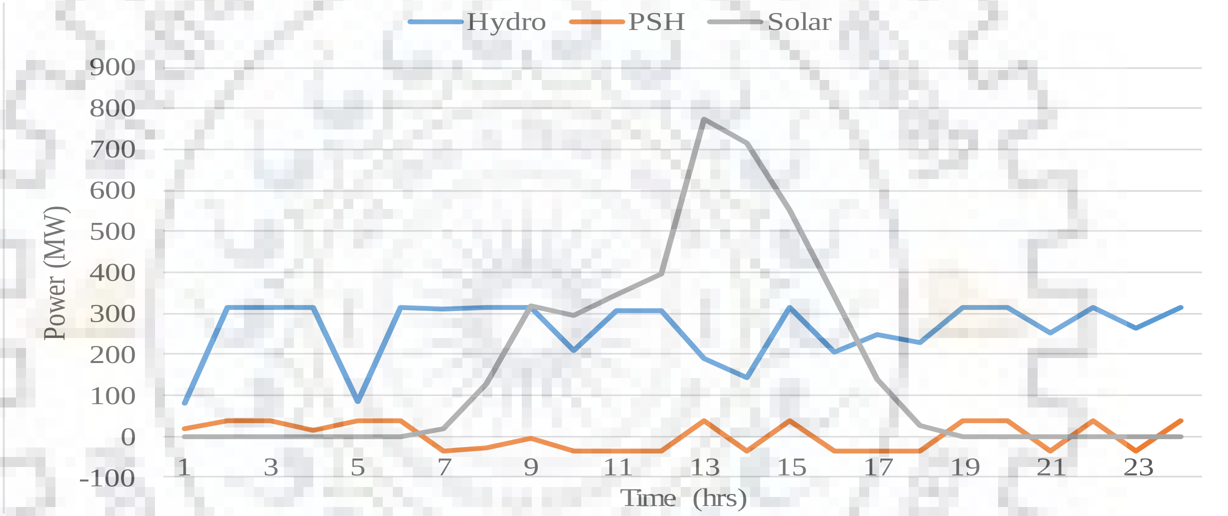

Figure 5.11: Power scheduled to Hydro, PSH and solar plant in case 2 for summer

In this case, there is no curtailment of solar power in winter season and 1.94% curtailment of solar energy in summer season. The curtailment of solar energy is reduced by the implementation of dynamic line rating concept. The cost of power generation from thermal power plant is also reduced by 1.32% for summer and 1.27% for winter. Surplus power ($\hat{S}$) flowing through line also reduced by 8.47% for summer case and 8.02% for winter case shown in figure (5.12) and figure (5.13) respectively. For this case voltage variation of bus 46 for both seasons is given in figure (5.14).

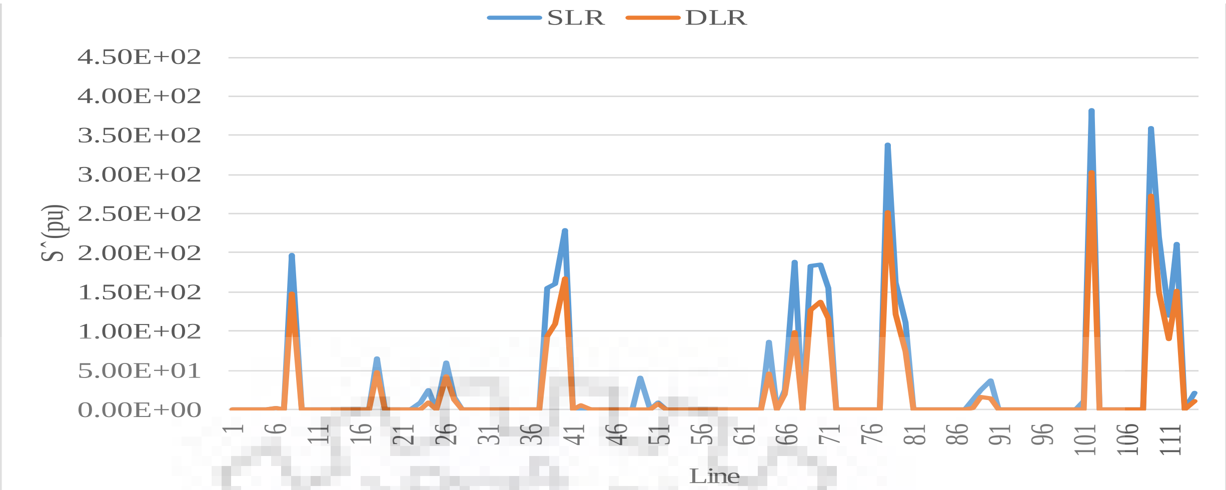

Figure 5.12: Surplus power (S´) of each line with SLR (case 1) and DLR (case 2) for summer

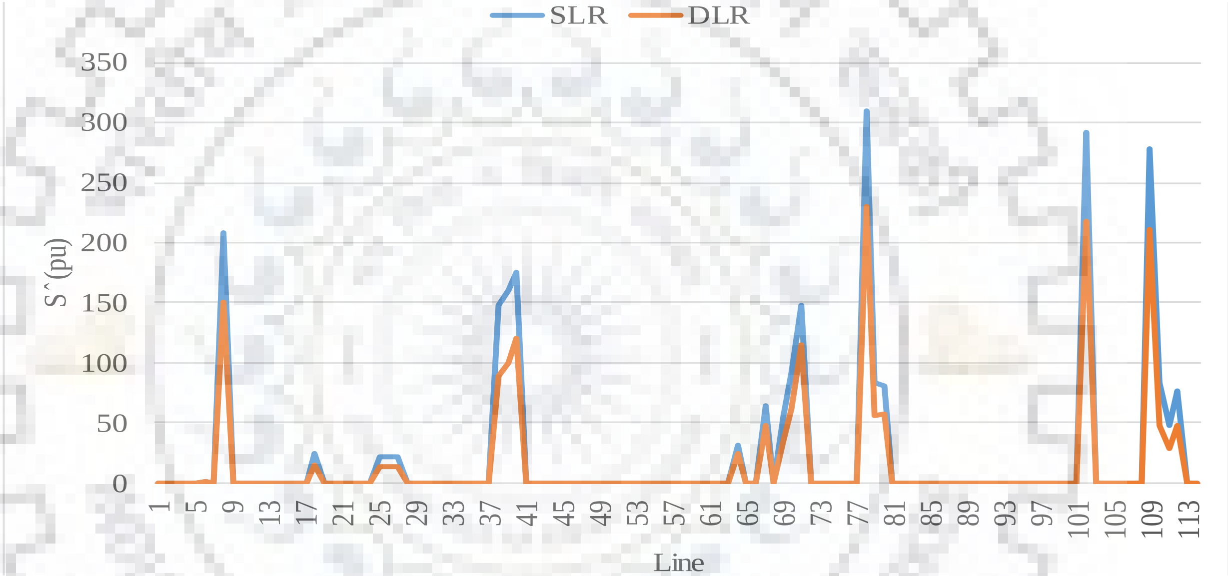

Figure 5.13: Surplus power (S´) of each line with SLR (case 1) and DLR (case 2) for winter

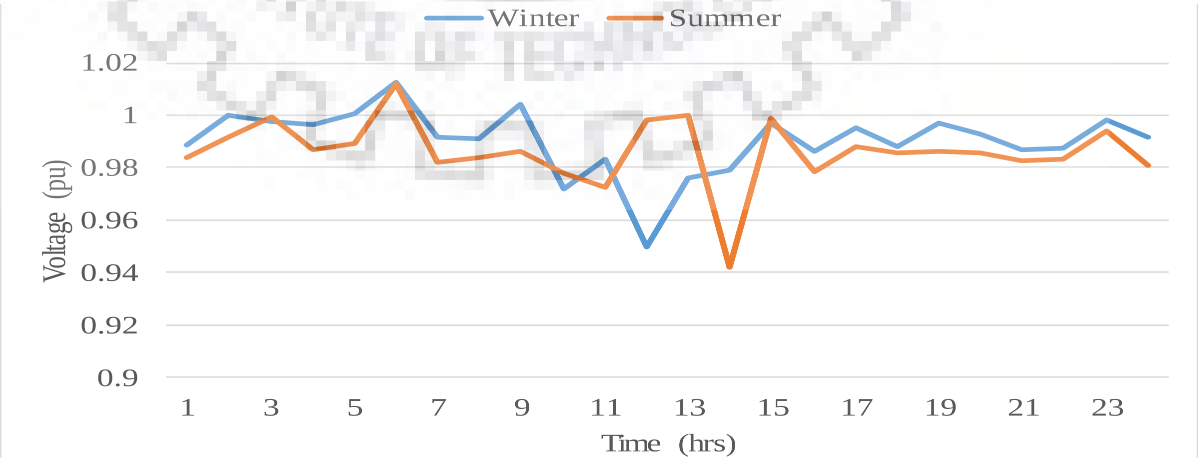

Figure 5.14: Voltage of bus 46 in case 2

CASE 3 : In this case, minimization of objective function 1 equation (5.15) has been done considering dynamic line rating and ZIP load coefficient calculated in section (5.7) and (5.8) respectively.

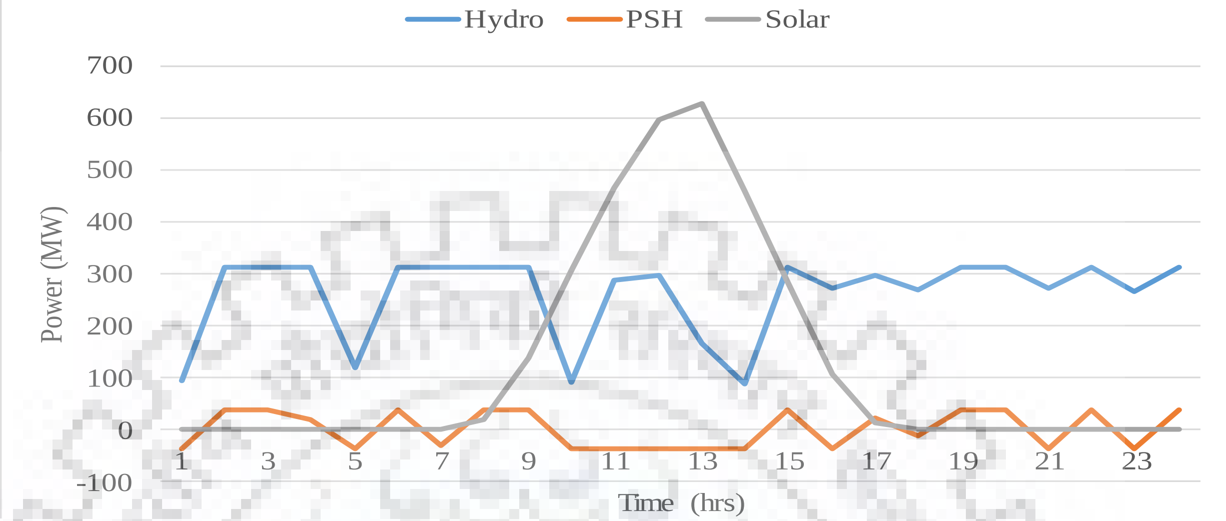

Figure 5.15: Power scheduled to Hydro, PSH and solar plant in case 3 for winter

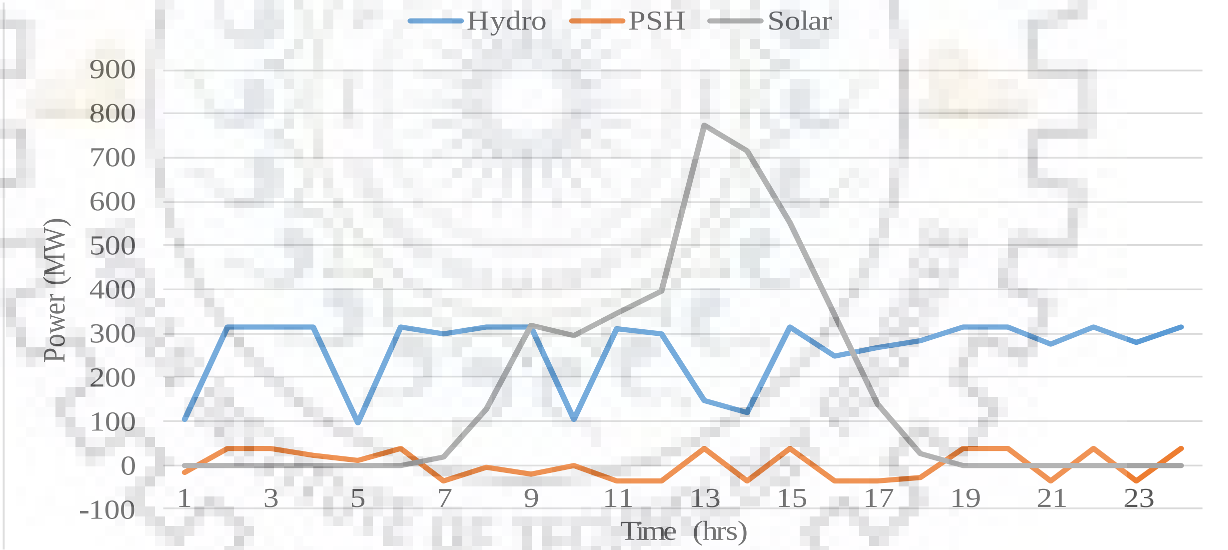

Figure 5.16: Power scheduled to Hydro, PSH and solar plant in case 3 for summer

Power scheduled to hydro, pumped hydro and solar winter and summer weather is shown in figure (5.15) and figure (5.16) respectively. In this case, curtailment of solar power is 2.26% for summer and no curtailment for winter. Voltage profile of bus 46 for both weather shown in figure (5.17). Most of the time on all buses voltage is below 0.95 pu, which is not desired for load. In this case load demand is dynamic and is depended on voltage and cost of thermal power generation is dependent on load demand, so objective function forces to load demand to be minimum and to make load demand low, voltage is also reduce below 0.95 pu.

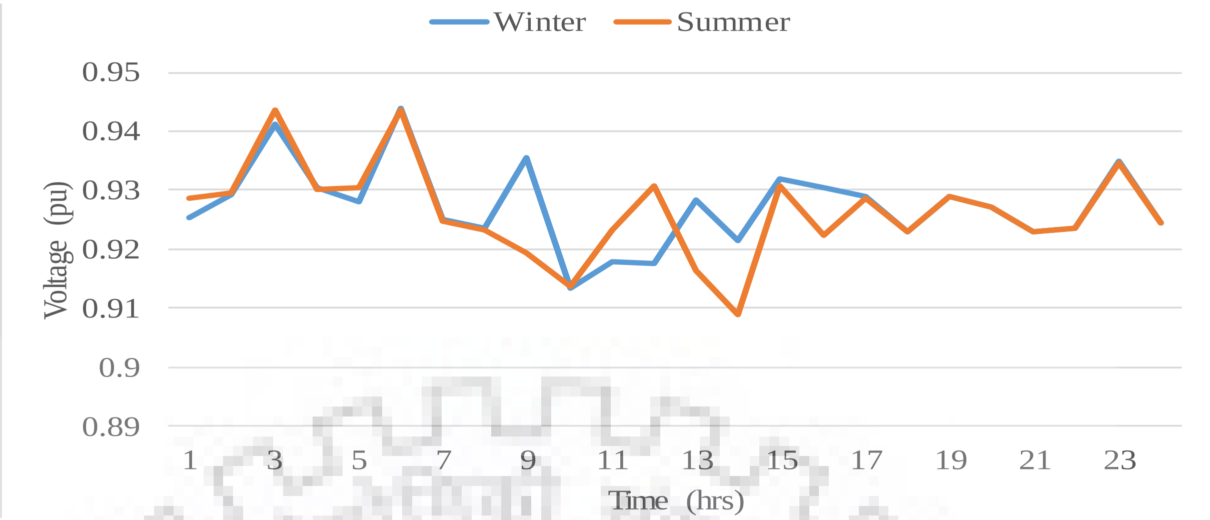

Figure 5.17: Voltage of bus 46 in case 3

CASE 4 : In previous case voltage falls below 0.95 pu, which is not desired to load. Here a penalty factor on voltage deviation from nominal voltage is introduced. Objective function 2 equation (5.16) includes penalty factor on voltage fluctuation. In this case, same scheduling problem with dynamic load and dynamic load has been solved for both weather condition with objective function 2 equation (5.16). This case has been solved for four different penalty factor *(k2)* introduced in section (5.4).

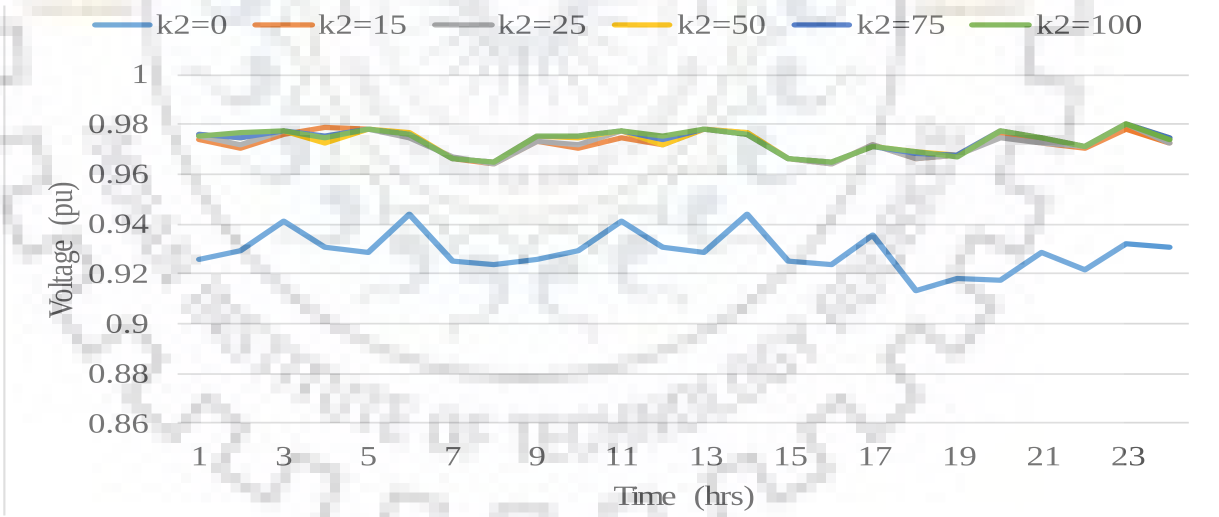

Figure 5.18: Voltage of bus 46 for different penalty factor (k2) in winter for case 4

Figure (5.18) and figure (5.19) shows voltage without penalty factor k2 and with different value of k2 for winter and summer respectively. Inclusion of penalty factor for voltage deviation in objective function improves voltage towards the nominal voltage of bus. The inclusion of penalty factor *k2* will also affect the total fuel cost of thermal power generation, curtailment of solar power and surplus power $(\widehat{S})$ flowing through the lines. Total fuel cost of thermal power generation and surplus power $(\widehat{S})$ will increase by inclusion of penalty factor *k2*, because for minimization of objective function the deviation in voltage will be forced towards zero and it will affect the power scheduled to all the generators. Figure (5.20) and figure (5.21) shows the curtailment of solar power, increment in fuel cost of thermal power generation and increment in surplus power $(\widehat{S})$ through line with different value of penalty factor *k2* as compare to result without penalty factor *k2* of case 3.

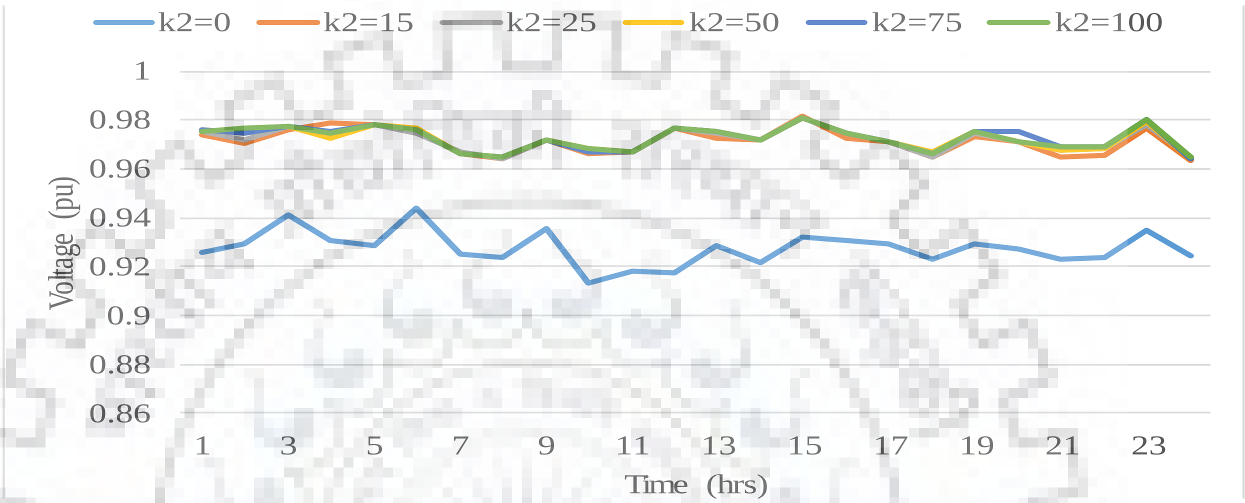

Figure 5.19: Voltage of bus 46 for different penalty factor (k2) in summer for case 4

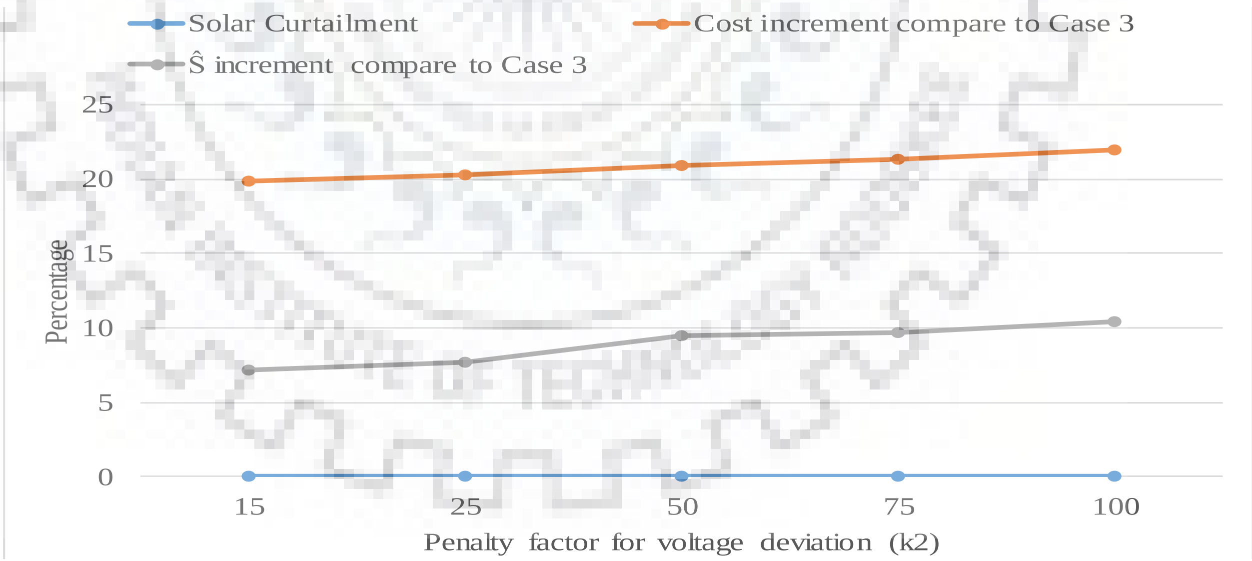

Figure 5.20: Solar curtailment, cost increment and Ŝ increment with diffrent penalty factor (k2) for winter

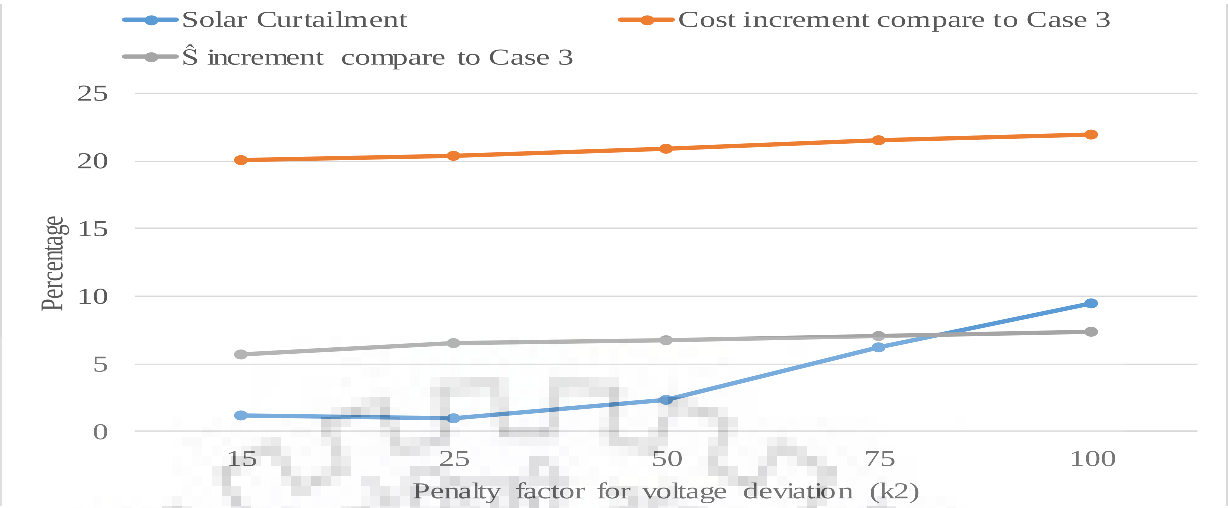

Figure 5.21: Solar curtailment, cost increment and Ŝ increment with different penalty factor (k2) for summer

In figure (5.20), results for winter season shows there is no curtailment of solar power and fuel cost for thermal power generation and $\hat{S}$ is minimum for k2=15. Therefore, best way for scheduling in winter season with better voltage profile is to take k2=15. In figure (5.21) for summer season, solar power curtailment is minimum for k2=25, curtailment of solar for k2=15 is also approximately same as for k2=25, but cost of fuel for thermal generation and $\hat{S}$ is slightly more for k2=25 as compare to k2=15. Therefore, for summer season scheduling can be done either with k2=15 or 25, depending on priority of solar curtailment and fuel cost of thermal generators.

5.10 Summary

In this chapter, a new problem has been formulated to load scheduling including penalty factor on overloading of line and penalty on voltage deviation from its nominal value. The concept of Dynamic line rating and a voltage dependent ZIP load are introduced here. The results of this chapter shows that with a smart scheduling method and proper utilization of the installed lines of power system renewable energy integration can be increased with a little upgradation of some lines. The results show how the dynamic line rating is affecting the curtailment of renewable energy and fuel cost of thermal power generation.

CHAPTER-6

Conclusion

The aim of this work was to plan to penetrate high renewable energy with minimum curtailment in a existing transmission system. The chapter 4 shows the impact of inclusion of storage type unit on renewable energy integration and its curtailment. Results of this chapter shows to handle uncertainty of availability of renewable energy and fluctuation of load demand with minimum curtailment of renewable energy, inclusion of more energy storage type unit in system is required. This result also shows fuel cost of thermal power generation reduces significantly by inclusion of pumped storage hydro type unit. The reduction in power scheduled to thermal power generating unit also reduces the emission of harmful gases in environment.

Results of chapter 5 shows with proper forecasting of weather and inclusion of concept of dynamic line rating in an old existing power system network more renewable energy can be injected on transmission level. The results of this chapter shows maximum utilization of power handling capacity of transmission line for solar power integration. A penalty factor for voltage fluctuation has been decided for a system having voltage dependent ZIP load model and dynamic line rating with minimum possible curtailment of renewable energy and minimum congestion of network with better voltage profile.

The results of this works concludes, with installation of some storage type unit and using dynamic line rating for load scheduling in an old existing power system network high renewable energy can be penetrated with a little upgradation of transmission system.

Appendix A

IEEE 14 bus system line data.

Table A.1: IEEE 14 bus system line data

Line number	From bus	To bus	Line reactance (pu)	MVA rating
1	1	2	0.05917	120
2	1	5	0.22304	65
3	2	3	0.19797	36
4	2	4	0.17632	65
5	2	5	0.17388	50
6	3	4	0.17103	65
7	4	5	0.04211	45
8	4	7	0.20912	55
9	4	9	0.55618	32
10	5	6	0.25202	14
11	6	11	0.1989	18
12	6	12	0.25581	32
13	6	13	0.13027	32
14	7	8	0.17615	32
15	7	9	0.11001	32
16	9	10	0.0845	32
17	9	14	0.27038	32
18	10	11	0.19207	12
19	12	13	0.19988	12
20	13	14	0.34802	12

Appendix B

Bus data and line data of Uttar Pradesh (India) state electricity board 75-bus transmission system.

Base voltage = 400 KV, S_{base}=100MVA

Table B.1: Generator data

Bus number	Nominal Voltage(pu)	P_{max}(MW)	P_{min}(MW)	Q_{max}(MVAR)	Q_{min}(MVAR)
1	1.03	900	100	400	0
2	1.03	300	100	96	0
3	1.05	200	40	83	0
4	1.03	170	40	60	0
5	1.05	240	0	31	0
6	1.05	120	0	20	0
7	1.05	100	0	19	0
8	1.05	100	20	68	0
9	1.05	570	60	250	0
10	1.02	120	30	56	0
11	1.02	200	40	105	0
12	1.05	1800	1800	344	0
13	1.05	900	900	280	0
14	1.03	150	150	84	0
15	1.02	454	454	35	-30

Table B.2: Load bus data

Bus no	Real (MW)	Reactive (MVAR)
16	-58.69	27.56
17	0	0
18	0	0
19	0	0
20	156.37	33.93
21	0	0
22	0	0
23	0	0
24	227.95	40.53
25	210.48	43.43
26	0	0
27	306	40.7
28	127.75	28.35
29	0	0
30	226.46	44.24
31	0	0

32	78.11	11.59
33	0	0
34	81.7	83.84
35	0	0
36	0	0
37	144.28	40.93
38	0	0
39	85.12	29.46
40	0	0
41	0	0
42	1000	0
43	0	0
44	0	0
45	0	0
46	156.32	83.36
47	74.55	8.77
48	50.83	13.97
49	85.72	51.58
50	202.1	74.94
51	57.76	0.62
52	98.27	-18.15
53	82.63	-0.33
54	161.95	29
55	274.23	31.08
56	140.28	34.32
57	152.78	18.53
58	94.19	11.29
59	121.89	11.01
60	74.2	7.42
61	106.5	6.58
62	100.18	18.13
63	58.01	5.31
64	56.79	13.33
65	147.84	12.81
66	31.74	15.18
67	96.43	10.55
68	42.87	33.6
69	55.94	32.53
70	23.34	2.3
71	91.73	21.36
72	52.52	11.76
73	477	0
74	288	0
75	-444	0

Table B.3: Line data

Line number	From Bus	To Bus	R(pu)	X(pu)
1	17	1	0.00073	0.0146
2	16	2	0.00123	0.02469
3	18	3	0	0.02917
4	28	4	0.00306	0.06135
5	31	5	0.00235	0.0471
6	32	6	0.00514	0.10285
7	33	7	0.00549	0.10978
8	34	8	0	0.0486
9	36	9	0.00049	0.01943
10	24	10	0.00243	0.0486
11	40	11	0.0077	0.0272
12	41	12	0.00016	0.00591
13	42	13	0.0003	0.01199
14	43	14	0	0.02841
15	44	15	0	0.02273
16	19	20	0.0013	0.05208
17	19	20	0.0013	0.05208
18	17	16	0.00065	0.02604
19	22	25	0.0013	0.05208
20	22	25	0.0013	0.05208
21	23	24	0.0013	0.052
22	23	24	0.0013	0.052
23	26	27	0.0013	0.052
24	26	27	0.0013	0.052
25	29	30	0.00129	0.05208
26	29	30	0.00129	0.05208
27	29	30	0.00129	0.05208
28	36	37	0.0013	0.05208
29	36	37	0.0013	0.05208
30	38	39	0.0013	0.05208
31	45	44	0.00112	0.04444
32	45	44	0.00112	0.04444
33	16	46	0.0162	0.0776
34	16	46	0.0162	0.0776
35	16	50	0.02979	0.14238
36	16	50	0.02979	0.14238
37	16	50	0.02979	0.14238
38	17	19	0.00468	0.0477
39	17	23	0.00785	0.0799
40	19	26	0.00264	0.02997
41	47	50	0.01093	0.05221
42	47	67	0.00662	0.03164

43	24	27	0.00505	0.02416
44	24	54	0.02582	0.12342
45	24	54	0.02582	0.12342
46	25	43	0.0127	0.06416
47	54	28	0.0106	0.0506
48	28	43	0.0058	0.029
49	28	56	0.0037	0.0178
50	56	30	0.0049	0.0237
51	30	57	0.0075	0.0384
52	53	30	0.00679	0.03412
53	53	61	0.00666	0.0339
54	30	61	0.0144	0.0731
55	57	58	0.0067	0.0339
56	57	59	0.00583	0.02956
57	59	39	0.0141	0.0718
58	39	31	0.0144	0.0725
59	54	63	0.0099	0.0509
60	55	63	0.0078	0.0398
61	61	62	0.0116	0.0583
62	62	32	0.0138	0.07
63	62	32	0.0138	0.07
64	35	36	0.00479	0.0488
65	46	37	0.01732	0.08784
66	19	36	0.00254	0.02584
67	17	35	0.00051	0.00517
68	40	48	0.0083	0.0424
69	74	41	0.00927	0.09429
70	74	41	0.00833	0.08478
71	26	41	0.00823	0.08375
72	48	49	0.0093	0.0475
73	49	40	0.0133	0.0668
74	38	29	0.0037	0.03762
75	38	22	0.00325	0.03307
76	18	47	0.00437	0.02552
77	30	65	0.00248	0.01186
78	41	42	0.00031	0.0031
79	42	74	0.00918	0.09306
80	23	74	0.00015	0.00155
81	24	67	0.00124	0.00593
82	18	68	0.00336	0.01963
83	18	71	0.01344	0.07852
84	27	68	0.01344	0.07852
85	27	71	0.00336	0.01963
86	43	58	0.01315	0.06696
87	43	56	0.00499	0.02397

88	55	44	0.01996	0.09588
89	55	44	0.01996	0.09588
90	73	45	0.00121	0.01109
91	29	22	0.0026	0.02646
92	21	65	0.00083	0.00396
93	34	54	0.0354	0.1702
94	34	54	0.0354	0.1702
95	39	33	0.0141	0.0718
96	39	33	0.0141	0.0718
97	31	32	0.0005	0.00253
98	20	40	0.0116	0.0588
99	20	40	0.0116	0.0588
100	21	30	0.00695	0.035
101	28	55	0.01998	0.010127
102	35	41	0.00031	0.0031
103	37	69	0.01212	0.061
104	25	60	0.0166	0.0843
105	51	52	0.0155	0.0794
106	20	64	0.0183	0.0927
107	70	72	0.00878	0.0443
108	20	66	0.01325	0.06667
109	29	75	0.00051	0.00517
110	26	22	0.0065	0.06617
111	23	29	0.00806	0.08169
112	74	73	0.00559	0.05686
113	25	72	0.01598	0.08108
114	27	51	0.016	0.081

Appendix C

Wind speed and temperature around the lines.

Table C.1: Weather data of 13th February 2019

Line number	Temperature (°C)				Wind speed(mph)			
	Early Morning	Afternoon	Evening	Late night	Early Morning	Afternoon	Evening	Late Night
1	16	29	23	15	4	4	4	4
2	16	29	23	15	4	4	4	4
3	15	26	20	15	2	3	4	5
4	12	24	18	15	4	3	4	6
5	12	23	18	14	4	4	5	7
6	12	24	20	14	4	3	4	4
7	14	24	17	14	4	4	3	6
8	14	28	22	16	5	4	6	6
9	16	28	20	15	4	4	5	4
10	13	25	20	14	4	2	4	6
11	14	24	19	15	4	4	2	2
12	16	30	21	13	2	6	4	3
13	19	29	23	15	4	4	4	4
14	16	24	19	15	6	3	4	6
15	18	25	19	15	7	2	5	5
16	16	29	23	15	4	4	4	4
17	16	26	18	14	3	4	5	4
18	15	26	20	15	2	3	4	5
19	15	24	17	13	4	5	4	3
20	15	24	13	13	4	5	4	3
21	13	25	20	14	4	2	4	6
22	13	25	20	14	4	2	4	6
23	16	25	19	15	2	3	4	4
24	16	25	19	15	2	3	4	4
25	15	23	19	14	7	2	4	5
26	15	23	19	14	7	2	4	5
27	15	23	19	14	7	2	4	5
28	16	26	18	14	5	6	7	6
29	16	26	18	14	5	6	7	6
30	14	24	17	14	4	4	3	6
31	18	25	19	15	7	2	5	5
32	18	25	19	15	7	2	5	5
33	18	29	23	15	4	4	4	4
34	18	29	23	15	4	4	4	4
35	18	29	23	15	4	4	4	4

36	18	29	23	15	4	4	4	4
37	18	29	23	15	4	4	4	4
38	15	24	20	14	4	3	4	4
39	15	25	20	14	6	2	4	6
40	19	26	18	14	3	4	5	4
41	13	25	20	14	4	2	4	6
42	13	25	20	14	4	2	4	6
43	16	25	19	15	4	4	6	6
44	13	25	20	14	4	2	4	6
45	13	25	20	14	4	2	4	6
46	15	24	17	13	6	7	7	5
47	12	24	18	15	4	3	4	6
48	16	24	19	15	6	3	4	6
49	12	24	18	15	4	3	4	6
50	15	23	19	14	7	2	4	5
51	15	24	20	14	9	4	6	7
52	15	23	19	14	7	2	4	5
53	15	23	19	14	7	2	4	5
54	15	23	19	14	7	2	4	5
55	15	24	20	14	9	4	6	7
56	14	24	18	13	6	4	4	5
57	14	24	18	13	6	4	4	5
58	14	24	17	14	5	4	3	6
59	14	28	22	16	5	4	6	6
60	18	25	19	15	7	2	5	5
61	12	24	20	14	4	3	4	4
62	12	24	20	14	4	3	4	4
63	12	24	20	14	4	3	4	4
64	16	25	19	14	3	6	7	4
65	16	26	20	15	4	7	6	4
66	16	26	20	15	4	7	6	4
67	16	28	20	15	4	4	5	4
68	16	24	19	14	4	4	6	4
69	16	24	18	14	4	5	10	5
70	16	24	18	14	4	5	10	5
71	16	30	21	13	2	6	4	3
72	16	24	19	15	4	5	6	4
73	16	24	19	15	4	5	6	4
74	15	21	17	14	5	7	8	3
75	14	19	17	13	6	7	9	6
76	15	26	20	15	2	3	4	5
77	15	20	18	14	7	11	11	4
78	16	30	21	13	2	6	4	3
79	19	29	23	15	4	4	4	4
80	16	24	18	14	4	5	10	5

81	13	25	20	14	4	2	4	6
82	15	26	20	15	2	3	4	5
83	15	26	20	15	2	3	4	5
84	15	24	18	14	4	6	6	3
85	15	24	18	14	4	6	6	3
86	16	24	19	15	6	3	4	6
87	16	24	19	15	6	3	4	6
88	18	25	19	15	7	2	5	5
89	18	25	19	15	7	2	5	5
90	16	21	17	15	7	10	11	6
91	16	23	17	14	4	5	6	4
92	15	20	18	14	7	11	11	4
93	14	28	22	16	5	4	6	6
94	14	28	22	16	5	4	6	6
95	14	24	17	14	4	4	3	6
96	14	24	17	14	4	4	3	6
97	12	24	20	14	4	3	4	4
98	14	24	19	15	4	4	2	2
99	14	24	19	15	4	4	2	2
100	15	20	18	14	7	11	11	4
101	12	24	18	15	4	3	4	6
102	16	30	21	13	2	6	4	3
103	16	26	20	15	4	7	6	4
104	14	19	17	13	6	7	9	6
105	16	22	18	15	4	4	5	3
106	16	23	18	14	3	4	4	3
107	15	20	17	15	6	7	8	4
108	17	28	21	14	5	7	8	5
109	14	24	17	14	4	4	3	6
110	14	19	17	13	6	7	9	6
111	16	24	18	14	4	5	10	5
112	16	21	17	15	7	10	11	6
113	15	21	17	14	5	7	8	3
114	16	22	18	15	4	4	5	3

Table C.2: Weather data of 13th June 2018

Line Number	Temperature (°C)				Wind speed(mph)			
	Early Morning	Afternoon	Evening	Late night	Early Morning	Afternoon	Evening	Late Night
1	35	42	36	32	4	4	9	6
2	29	38	39	32	9	3	7	4
3	32	42	36	28	6	6	5	5
4	31	38	35	29	4	3	7	8
5	31	44	42	28	4	9	8	4

6	30	38	43	30	5	7	4	5
7	32	40	38	33	9	8	7	5
8	33	42	40	29	9	8	3	7
9	35	41	36	33	6	8	9	6
10	30	44	37	29	7	7	7	7
11	31	41	35	28	7	7	3	6
12	31	39	39	31	2	7	5	5
13	31	43	36	33	6	4	7	6
14	30	38	43	31	2	6	9	2
15	29	42	38	27	5	9	6	5
16	32	42	43	29	5	2	7	9
17	30	39	41	28	2	6	7	8
18	34	38	40	28	2	5	9	7
19	32	38	39	27	9	9	3	8
20	35	38	41	32	6	7	5	8
21	35	39	35	32	5	9	4	8
22	33	45	41	29	5	6	7	8
23	30	37	42	32	3	8	9	9
24	35	45	35	32	3	5	6	3
25	33	37	42	31	5	6	8	5
26	34	45	41	29	4	3	4	6
27	32	39	43	29	8	7	6	4
28	33	41	37	28	6	9	5	2
29	29	44	42	29	5	6	9	9
30	35	44	40	30	3	6	7	7
31	33	38	36	30	9	8	8	3
32	29	42	37	31	7	3	3	3
33	33	45	41	30	8	9	4	7
34	31	45	41	32	7	2	8	5
35	29	38	36	28	9	6	3	2
36	30	38	39	30	9	7	2	5
37	30	43	37	31	4	6	5	3
38	30	37	42	28	7	6	9	8
39	33	37	38	31	7	4	4	9
40	34	41	42	27	6	6	6	2
41	32	44	37	30	8	9	5	7
42	32	45	42	32	3	7	2	7
43	33	37	37	30	3	9	6	4
44	35	41	41	30	2	3	8	8
45	33	44	35	28	3	6	4	4
46	33	44	40	27	6	3	2	2
47	35	44	40	32	6	6	4	3
48	32	44	38	32	5	7	7	8
49	31	43	37	29	4	3	4	7
50	35	38	41	28	2	8	7	8

51	32	41	36	29	8	5	2	7
52	33	38	39	32	7	9	7	8
53	33	44	35	32	5	4	5	2
54	33	45	37	31	4	2	2	5
55	30	38	39	33	8	4	5	4
56	29	44	42	33	8	2	7	6
57	31	40	36	28	8	9	9	9
58	34	40	41	31	5	2	9	4
59	32	39	40	30	9	3	9	6
60	32	44	35	27	8	2	9	2
61	32	43	39	32	2	3	9	3
62	34	41	43	30	4	2	8	8
63	33	43	36	32	8	7	6	3
64	33	45	41	27	5	6	5	8
65	30	38	40	29	5	4	3	4
66	32	39	40	31	9	3	7	7
67	32	42	39	28	9	3	9	2
68	31	44	40	31	8	5	4	8
69	32	44	38	29	6	2	8	6
70	31	40	36	32	9	7	2	9
71	34	38	37	31	6	6	5	4
72	31	38	39	29	3	4	4	5
73	33	40	40	29	4	8	3	3
74	32	44	42	29	4	8	7	9
75	33	39	43	33	6	4	4	5
76	35	43	36	30	2	6	9	2
77	32	42	40	30	2	5	6	7
78	35	37	40	30	3	4	8	6
79	30	43	39	33	9	8	2	4
80	34	44	38	28	8	9	7	8
81	29	41	39	32	7	7	6	8
82	32	44	40	27	9	3	8	4
83	29	38	43	29	10	3	7	6
84	34	43	36	32	10	6	9	5
85	30	44	41	29	3	4	9	3
86	30	44	40	31	9	4	3	6
87	30	39	42	30	6	6	3	9
88	33	39	36	27	2	3	8	3
89	30	41	37	31	4	7	2	9
90	31	40	36	31	9	2	5	6
91	34	41	39	31	8	2	4	5
92	32	45	41	29	2	4	8	3
93	35	42	37	30	7	2	3	4
94	29	45	37	31	8	9	8	5
95	32	41	38	32	4	8	8	6

96	32	40	39	27	2	5	6	5
97	32	43	41	28	4	3	4	8
98	34	43	39	31	3	5	2	9
99	30	41	38	32	6	5	7	8
100	31	37	42	33	5	7	2	5
101	29	38	43	28	5	5	2	7
102	35	43	40	29	9	9	3	7
103	34	42	36	31	5	9	5	3
104	34	37	40	29	4	9	7	6
105	30	41	38	32	2	4	8	4
106	31	43	43	29	4	4	6	6
107	30	38	37	28	4	9	2	9
108	32	39	41	31	2	3	4	5
109	34	44	39	28	7	3	7	2
110	33	38	37	32	2	6	8	9
111	33	44	40	32	7	9	4	9
112	33	44	35	30	5	5	6	5
113	33	37	37	27	4	3	8	4
114	34	40	35	28	7	2	6	8

Appendix D

Type of load categorized in four types with the help of research about the area on internet.

Table D.1: Type of loads

Bus number	Industrial Load (%)	Commercial Load (%)	Residential Load (%)	Agriculture Load (%)
16	5	15	55	25
17	10	20	50	10
18	10	15	50	25
19	5	15	60	20
20	5	15	55	25
21	25	30	25	20
22	30	30	25	15
23	25	20	35	20
24	40	20	30	10
25	30	30	25	20
26	5	10	60	25
27	20	40	35	5
28	3	20	60	17
29	20	12	50	18
30	15	15	60	10
31	30	20	40	10
32	30	20	40	10
33	10	10	70	10
34	5	5	70	20
35	5	5	72	18
36	8	20	60	12
37	12	16	62	10
38	14	16	60	10
39	14	16	60	10
40	5	15	65	15
41	8	20	60	12
42	4	16	65	15
43	8	10	67	15
44	7	9	70	14
45	11	9	70	10
46	8	12	65	15
47	9	16	66	9
48	9	18	65	8
49	8	24	63	5
50	9	18	58	15
51	6	12	70	12
52	5	10	70	15
53	8	10	60	22

54	5	5	70	20
55	8	8	61	23
56	15	10	60	15
57	25	30	40	5
58	15	10	65	10
59	15	20	50	15
60	12	10	60	18
61	7	8	60	25
62	8	9	65	18
63	10	12	66	12
64	10	15	65	10
65	14	15	58	13
66	5	10	70	15
67	18	10	61	11
68	8	10	62	20
69	7	12	65	16
70	10	13	63	14
71	5	8	70	17
72	12	18	65	5
73	20	21	55	4
74	25	18	52	5
75	12	10	65	13

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