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DYNAMIC APPROACH FOR OPTIMAL GENERATON SCHEDULING IN MODERN POWER SYSTEMS

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Abstract
In recent years, the penetration of renewable power generation has increased substantially, and is expected to grow in the future. These renewable energy sources are environmentally friendlier compared to the conventional thermal energy sources. Wind and solar energy sources are variable as their electrical power generation varies based on the availability of wind and sun. The load demand is also varies with time, and our power system is designed to handle that variability.The aim of electric supply utility has been identified as to provide the smooth and adequate electric energy to the consumers without any disturbances. Here, one thing should be ensured that electrical power is generated with minimum generation cost. Hence in order to achieve an economic operation, the total demand must be appropriately shared among the all generating units. This research work aims to solve Economic load dispatch Using POWER WORLD SIMULATOR Software.This minimize the total generation cost for the system with satisfied all equality and inequality constraints.
Keywords-PV, Wind, ELD, OPF, etc.

I. INTRODUCTION

In recent years, the penetration of renewable power generation has increased substantially, and is expected to grow in the future. These renewable energy sources are environmentally friendlier compared to the conventional thermal energy sources. Wind and solar energy sources are variable as their electrical power generation varies based on the availability of wind and sun. The load demand is also varies with time, and our power system is designed to handle that variability. The real time changes to the load (minute to- minute) are generally small. But, due to renewable energy resources, the variations in power generation in real time are considerable. The main difference between load and renewable energy resources (RERs) is that load variations are better understood than RERs variations. An important problem with the integration of RERs is that the future solar irradiation/wind speed is an unknown at any given time. When the scheduling is done by real time economic dispatch (RTED), the range of uncertainty is smaller as the forecast is more accurate compared to longer term (i.e., 5 h horizon and the 24 h horizon), when the scheduling is done by short-term unit commitment and day-ahead market, respectively. A perfect forecast eliminates uncertainty, but there is still variability. For perfect forecasting cases (i.e., in real time), the only chance of imbalance is that the variability, occurring within the time resolution of scheduling period. Balancing generation and load demand instantaneously and continuously is very difficult task as the loads and generators are fluctuating constantly. As a result of varying wind speed and solar irradiation, wind and solar plants generate varying amounts of electricity. The intermittent/ uncertain nature of wind speed and solar irradiation represents the challenging constraint to the power system operators, as the supply and demand need to be balanced continuously in the real time. System Operator (SO) needs to not only procure sufficient fast resources, spread over the entire system, but also schedule them appropriately. Hence, compared to managing just the load variability, managing additional, large scale, renewable generation variability, involves considerable generation costs.

The operational costs of electrical power system increases, because the system operators are need to secure additional/extra operating flexibility on several time scales to balance the fluctuations and uncertainties in wind/solar PV power output. Therefore, the presence of any renewable source of power, increases balancing requirement and associated costs. Because of wind and solar variability, there has been wide spread interest in determining the increase in ancillary services needed to integrate wind and solar over various time scales.Economic load dispatch is one of the challenging non-convex optimization problems in power system, which is difficult to solve using the conventional methods. The real world input-output characteristics of the generating units are highly non-linear, non-smooth and discontinuous due to valve-point loading effect, prohibited zones, and generating ramp-rate limits.With large interconnection of the electricity networks, the energy crisis in the world and continuous rise in prices, it is very essential to reduce the running costs of electric energy. The main aim of modern electric power utilities is to provide high-quality reliable power supply to the consumers at the lowest possible cost while maintaining all the constraints. ELD is the method of determining the most efficient, low-cost and reliable operation of a power system by dispatching the available generation to supply the load.The main outcomes of restructuring the power system are maximum exploitation of energy resources and flexibility without compromising system security.Optimal power flow (OPF) remains a widely-cultivated topic within power system research community since its inception about half-a-century ago. The prime objective of OPF is minimization of generation cost with optimal settings of control variables which are the generated real power and generator bus voltages of the network. While optimizing the generation cost, system constraints on generator capability, line capacity, bus voltage and power flow balance are to be satisfied.

Economic load dispatch:

Economic load dispatch is one of the challenging non-convex optimization problems in power system, which is difficult to solve using the conventional methods. The real world input-output characteristics of the generating units are highly non-linear, non-smooth and discontinuous due to valve-point loading effect, prohibited zones, and generating ramp-rate limits. With large interconnection of the electricity networks, the energy crisis in the world and continuous rise in prices, it is very essential to reduce the running costs of electric energy. The main aim of modern electric power utilities is to provide high-quality reliable power supply to the consumers at the lowest possible cost while maintaining all the constraints. ELD is the method of determining the most efficient, low-cost and reliable operation of a power system by dispatching the available generation to supply the load.

In Static ELD Problem, minimize the total generation cost in a single time interval (constant load).But in actual power system, with change in load demand, the generation has to be altered to meet the load demand. Hence, static ELD incorporates some difficulties in the system. To avoid this problem, dynamic ELD is implemented. In dynamic ELD, 24 connected series static ELD must be solved, covering supply and load demand over a24-hour intervals. In dynamic ELD, costs changing from one generation level to the other generation level. Conventional methods like lambda iteration method, linear programming, non-linear programming, quadratic programming, base point participation factor method, gradient descent technique, equal embedded algorithm and Newton-Raphson method can solve this ELD problems if the cost curves of the generator are piece-wise linear. Practically the input-output characteristics of the generator are highly non-linear and non-convex due to valve-point loading effect, prohibited operating zones, generator ramp rate limits. Thus the resultant ELD becomes a non-convex/non-smooth optimization problem, which is difficult to solve using this type conventional methods. Methods like fuzzy logic, ANN, GA, evolutionary technique, and particle swarm optimization (PSO) can solve non-convex optimization problems efficiently and achieve a fast and near global optimal solution. Among all, PSO was developed through simulation of a simplified social system, and has been found to be robust. The PSO can generate high-quality solutions within shorter computational time and stable convergence characteristics.The objective of ELD is to minimize the total active power generation cost including fuel cost, emission cost, maintenance cost, network losses cost by meeting the following constraints:

- Real power balance
- Network security constraints (maximum MW power flows of transmission lines)
- Downward-and-upward generator ramp-rate limits
- Lower and upper generation limits of each generating unit
- Prohibited operating zones Emission rate (SO2, CO2, NOx)

II. LITERATURE REVIEW

YahyaKabiriRenani et al. (2016) developed a self-generation scheduling method for a power generation company (GenCo) with renewable generation units. Problem formulation is done by game theory. Self-scheduling problem is developed considering: Disregarding the forecast error of hourly LMPs and variable RE, consider forecast error for LMP and except the ISO's market clearing process is simulated. Use 8 bus network systems. LMPs Calculated by incomplete information. The scheduling problem is modeled as a mixed-integer linear programming which is solved by a CPLEX solver in GAMS. Research gap is GenCo schedules its generation units without considering uncertainty and assumed fully competitive market and renewable unit size is small.

S. Surender Reddy et al. (2015) developed the evaluation of 'best-fit' participation factors by considering the minute-to-minute variability of solar, wind and load demand, for a scheduling period. The voltage, reactive power limits and line flow constraints are included for all minute-to-minute sub-intervals. Modified IEEE 30 bus and 118 bus system used.MATLAB optimization tool box is use. Research gap is the variable generation cost between two consecutive scheduling intervals is ignored and system operator will have to compulsorily use whatever generation is available from these sources.

S. Surender Reddy and P.R. Bijwe(2016) studied evaluation of ‘best-fit’ participation factors by taking into account the minute-to-minute variability of solar, wind and load demand for RT-OPF, and every 15 min variability for DA-OPF, over a scheduling period. Modified IEEE 30 bus system used. Research gap is Conventional DA-OPF and RT-OPF approaches ignores the impact of renewable power generation variability during the scheduling interval and the proposed RT-OPF and DA-OPF approaches do not consider line flow constraints.

Partha P. Biswas et al. (2017) developed optimal power flow combining stochastic wind and solar power with conventional thermal power generators in the system. The objective function considers reserve cost for overestimation and penalty cost for underestimation of intermittent renewable sources. Problem formulation is done by total generation cost thus consists of operation costs of all the generators are consider. SHADE algorithm is used with IEEE 30 bus system and MATLAB programme software. Research gap is all security constraints are not considered.

A.A.EI Desouky et al. (2001) developed prescheduling of the generating units using the ANN. Advanced ANN/GA/PL Hybrid techniques are used for effective solve the problem of short term generation scheduling. Objective function includes: Real power balance constraint, Hourly spinning reserve requirements, and Real power operating limits of generating units, UC up/down time, the transmission line constraints, and the ramp rate constraints. Research gap is this technique can be extended to also accommodate power loss in transmission lines and reactive power constraints.

Jorge Mart´ınez-Crespo et al. (2006) developed generalized Benders decomposition algorithm it is used to solve a multi-period dispatch problem with security constraints in a pool-organized electricity market model. Problem formulation is doing in the base of realistic model Spanish electricity market. Objective function is only energy bids divided in blocks as well as their bid prices are considered. IEEE 24 bus system is used with GAMS software. Research gap is not include fixed or start-up costs.

J. JeslinDrusilaNesamalar et al. (2016) analysed Optimal RES/NRES based generator rescheduling is performed for energy Management during congestion. Problem formulation: Cuckoo search algorithm used. Objective is based on to find out energy rescheduling cost. MATLAB software used with IEEE 30 bus and Real Time TN 106 bus system. Research gap is the seasonal changes will have impact on the congestion cost and Constrains (reactive power limit, Voltage limit and Line flow (MVA) limit) are not considered.

John Hetzer et al. (2008) develop a model to include the WECS in the ED problem and in addition to the classic economic dispatch factors. Problem formulation done on MATLAB optimization weibull pdf and objective is to find out overestimation and underestimation of available wind power. Research gap is only wind power is considered.

G. Yesuratnam and D. Thukaram (2006) address an approach for alleviation of network over loads in the day-to-day operation of power systems under deregulated environment. Problem formulation based on computational algorithm and objective is to minimize network over loads in the day-to-day operation of power systems by relative electrical distance concept. IEEE 39 bus New England system is used. Research gap is only line MW flow violations are considered.

Bounthanh et al. (2011) developed optimal generation scheduling method of renewable energy distribution. Problem formulation is based on Particle Swarm Optimization (PSO) algorithm and objective is to calculate optimal generation scheduling considering minimizing power line losses. IEEE standard 14 bus test system is use. Research gap is constraints Constrains (reactive power limit, Voltage limit and Line flow (MVA) limit) are not considered.

AlirezaSoroudi et al. (2013) developed Optimal Multi-area Generation Schedule Considering Renewable Resources Mix: a Real-Time Approach. Problem formulation is based on Multi Area Dynamic Economic Dispatch (MA-DED) algorithm and objective function includes: Hydro-thermal generating units, wind power generation and power pool market. Use three areas interconnected system. Research gap is the retailer is paid a fixed price for each MWh which sells to the customers.

Shubham Tiwariet al. (2018) developed Optimized Generation Scheduling of Thermal Generators Integrated to Wind Energy System with Storage. Problem formulation is based on Particle Swarm Optimization (PSO) algorithm and objective function is to formulate a short term deterministic Unit Commitment problem in renewable integrated environment with battery storage. Use three stage solution methodologies. Research gap is reactive power constraint is not considered.

QiushiXu et al. (2013) developed Real-Time Generation Dispatch and Communication Architecture of Smart Grid with Renewable Energy. Problem formulation is based on MATLAB tool box, objective is study of the real-time generation dispatch and use 10 unit test system. Research gap is considered only active power flow limit constrain.

Byeong-CheolJeonget al. (2019) developed Implementation of Optimal Two-Stage Scheduling of Energy Storage System Based on Big-Data-Driven Forecasting—An Actual Case Study in a Campus Microgrid.Problem formulation is based on completely open-source optimization module, objective is to minimize the Microgrid (MG) operation cost and use two-stage day-ahead and hour-scheduling algorithm. Research gap is the error rate of the forecasting module should be decreased and will also measure the required computation times.

III. WORK OBJECTIVES

Objectives: To minimize the total active power generation cost of units while satisfying all constraints.

- Objective functions:
  1. Quadratic (convex) cost function,
  2. Valve point loading effect (non-convex).
  3. Emission rate.
- Constraints:
  1. Real Power balance
  2. Generator output limit
  3. Generator Ramp-rate limits

4. Prohibited operating zone

- Including transmission line losses minimization.

a. Simple Economic Load dispatch : Generator Operating Cost Of Thermal Power Plant :

The fuel cost is meaningful in case of thermal and nuclear stations. The factor influencing power generation at minimum cost are operating efficiency of generator, fuel cost and transmission losses.

Hence the problem is to be determining the generation of different plants such that total operating cost is minimum.

An analytical expression for operating cost can be written as,

$$F(P_{gi}) = a_i P_{gi}^2 + b_i P_{gi} + c_i \quad Rs/h \qquad \text{……………… (1)}$$

Where,

ai,bi,ci are cost co-efficient for ith plant.

F(Pgi) is the total cost of generation.

Pgi is the generation of ith plant.

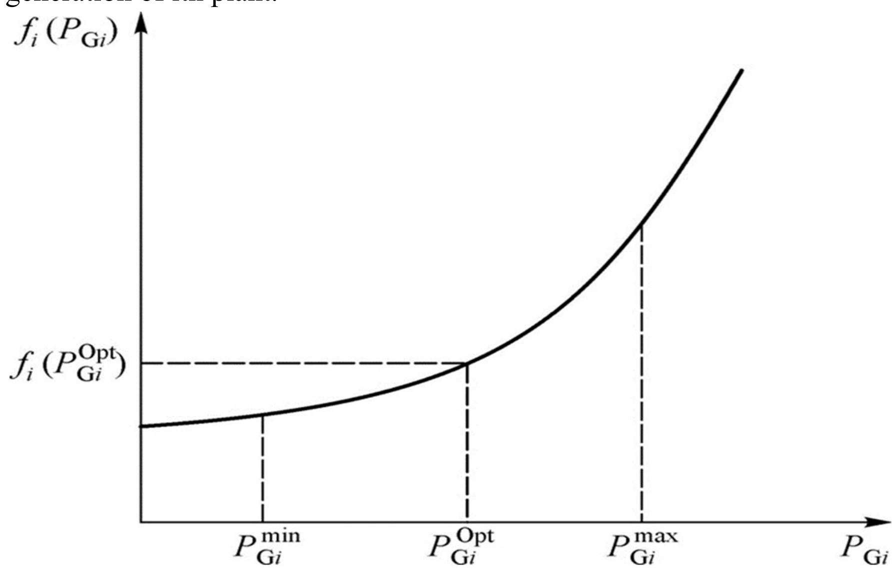

Fig.1 – operating cost of the fossil fired generator

Pgimin and Pgimax are the lower and upper limits on its output.

The Pgi^{min} is the minimum loading limit below which it is uneconomical to operate the unit and Pgi^{max} is the maximum output limit.

Thus, in competitive electricity market, ELD helps in saving a significant amount of revenue and to improve social welfare.

Problem Formulation:

The objective function is:

$$\min \ F(P_{g_i}) = \sum_{i=1}^{NG} a_i P_{g_i}^{\ 2} + b_i P_{g_i} + c_i \quad \text{.................................... (2)}$$

Subject to,

1. Equality constraints (energy balance equation),

$$\sum_{i=1}^{NG} P_{g_i} = P_D + P_L \quad \text{.. (3)}$$

2. Inequality constraints,

$$P_{g_i}^{min} \le P_{g_i} \le P_{g_i}^{max} \quad \text{... (4)}$$

Where,
is the load demand.
is the transmission power loss.
NG is the number of generator units.

Methods to solve economic load dispatch:
There are mainly two types of methods to solve economic load dispatch.
1. Conventional methods.
2. Soft-computing techniques.

1. Conventional methods:
1. Non-linear programming.
2. Linear programming.
3. Quadratic programming.
4. Generalized reduced gradient method.
5. Newton Raphson method.
6. Mixed-integer programming.
7. Interior point methods.
8. Lambda iteration method.
9. Gradient descent method.
10. Lagrange relaxation algorithm.

2. Soft-computing techniques:
1. Artificial neural network (ANN).
2. Evolutionary algorithms.
3. Tabu search (TS).
4. Genetic algorithms (GA).
5. Differential evolution.
6. Particle swarm optimization (PSO).
7. Cuckoo search algorithms.

8. Firefly algorithms.
9. Ant colony search algorithm.
10. Fuzzy logic.
11. Simulated annealing.

IV. SIMULATION IMPLEMENTATION USING POWER WORLD

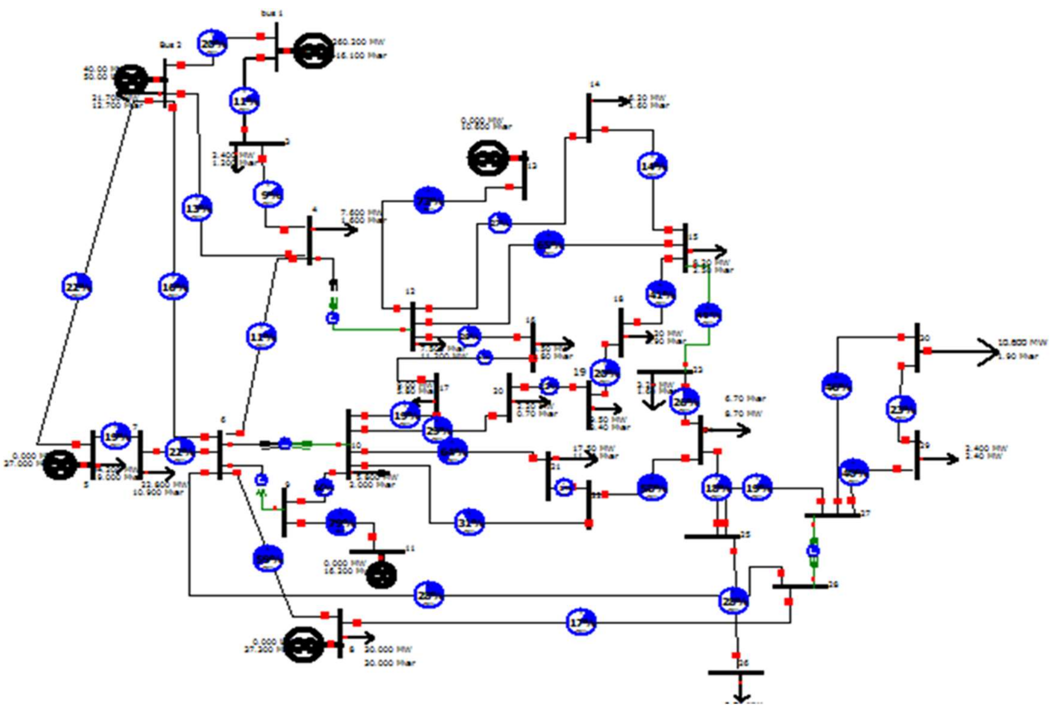

Fig.2- Power World Simulator for IEEE 30-bus system (Power world Load case)

Bus No	Volt(p.u)	Bus Voltage	Angle (Deg)	Gen MW	Gen MVAr
Bus 1	1.000	132	0.00	260.2	-16.1
Bus 2	1.000	132	-0.88	40	50
Bus 3	0.994	132	-1.43	0	0
Bus 4	0.993	132	-1.70	0	0
Bus 5	0.971	132	-2.30	0	37
Bus 6	1.000	132	-4.12	0	0
Bus 7	0.987	132	-3.37	0	0
Bus 8	0.992	132	-1.93	0	37.3
Bus 9	1.000	1.00	-1.71	0	0
Bus 10	0.969	33	-0.69	0	0
Bus 11	1.000	11	5.48	0	16.2

Bus 12	**0.954**	**33**	**-3.43**	**0**	**0**
Bus 13	**0.949**	**11**	**-3.58**	**0**	**10.6**
Bus 14	**0.937**	**33**	**-4.37**	**0**	**0**

Table-1Load Flow Results by Power World

Bus No	**Volt(p.u)**	**Bus Voltage**	**Angle (Deg)**	**Gen MW**	**Gen MVAr**
Bus 15	**0.955**	**33**	**-3.08**	**0**	**0**
Bus 16	**0.939**	**33**	**-4.01**	**0**	**0**
Bus 17	**0.939**	**33**	**-4.01**	**0**	**0**
Bus 18	**0.921**	**33**	**-4.65**	**0**	**0**
Bus 19	**0.916**	**33**	**-5.34**	**0**	**0**
Bus 20	**0.990**	**33**	**-2.23**	**0**	**0**
Bus 21	**0.924**	**33**	**-5.41**	**0**	**0**
Bus 22	**0.902**	**33**	**-6.92**	**0**	**0**
Bus 23	**0.882**	**33**	**-8.02**	**0**	**0**
Bus 24	**0.932**	**33**	**-4.21**	**0**	**0**
Bus 25	**0.933**	**33**	**-4.59**	**0**	**0**
Bus 26	**0.936**	**33**	**-4.36**	**0**	**0**
Bus 27	**0.947**	**33**	**-3.57**	**0**	**0**
Bus 28	**0.954**	**132**	**-3.43**	**0**	**0**
Bus 29	**1.000**	**33**	**1.29**	**0**	**0**
Bus 30	**0.896**	**33**	**-5.94**	**0**	**0**

Table-2 Load Flow Results by Power World

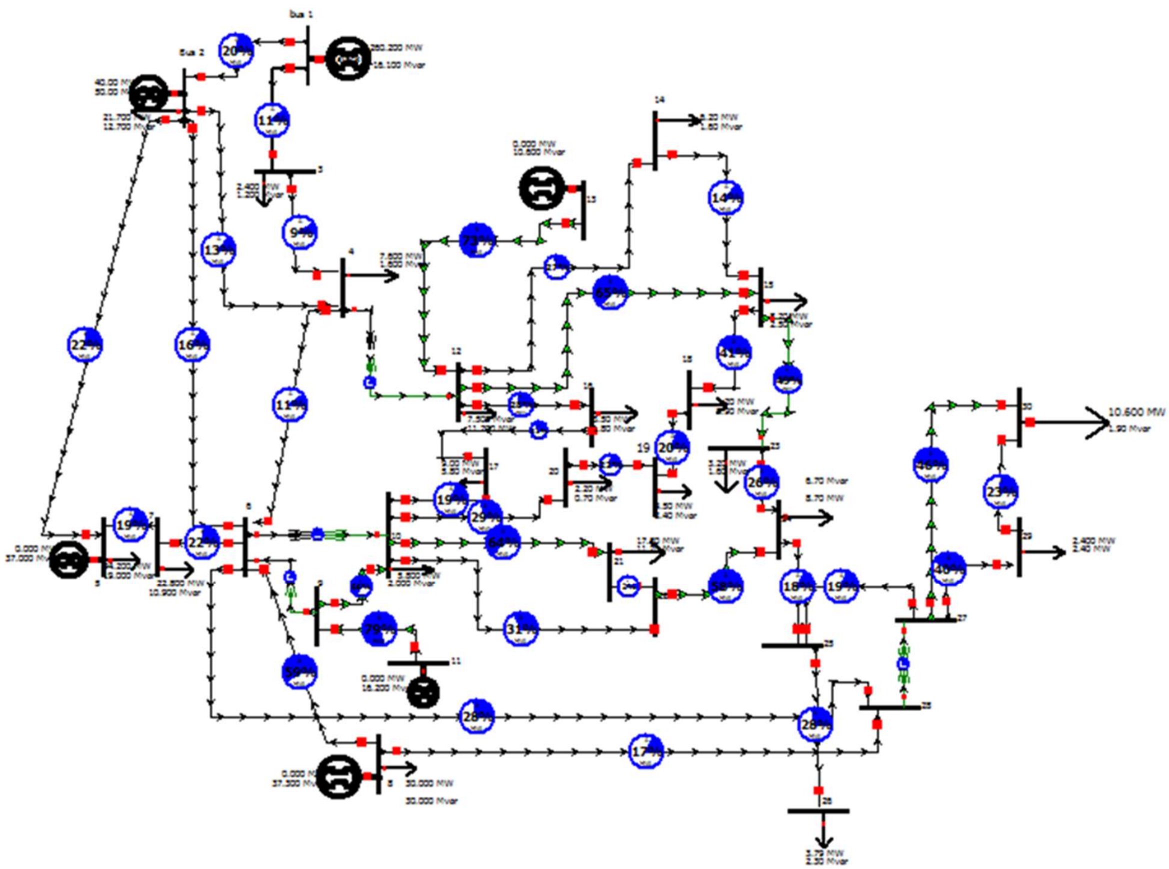

Fig.3- MI Power World Simulator for IEEE 30-bus system (Power world Load Flow)

Total Generation	300.20MW
Total Loss	15.6
Total Load	283.69MW

Table-3 Load Flow Result by POWER WORLD

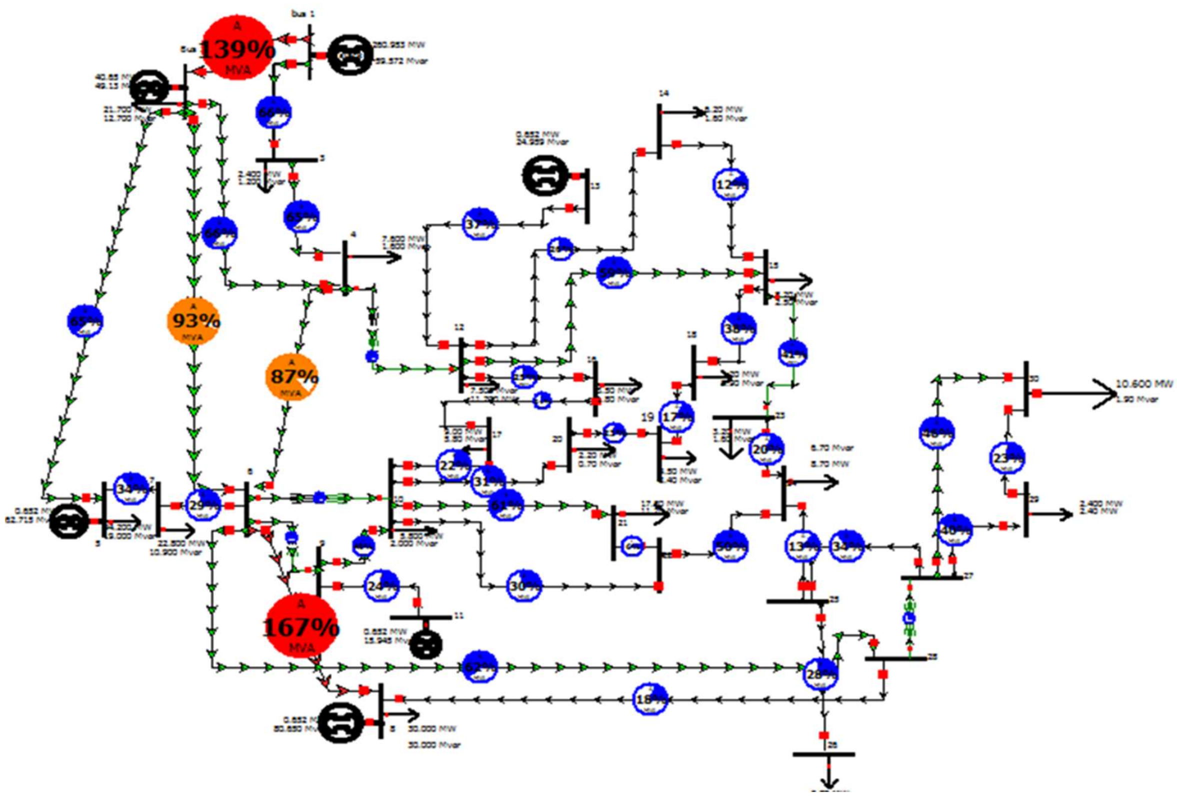

Fig.4- Power World OPF by POWER WORLD

Line No	Line Flow	Line No	Line Flow	Line No	Line Flow
Bus 1-2	24.1	Bus 4-12	3.9	Bus 21-22	-0.3
Bus 1-3	14.8	Bus 12-13	-43.5	Bus 15-23	6.8
Bus 2-4	8.5	Bus12-14	-8.3	Bus 22-24	8.2
Bus 3-4	12.3	Bus 12-15	19.6	Bus 23-24	3.5
Bus 2-5	27.1	Bus 12-16	8.2	Bus 24-25	-2.9
Bus 2-6	10.6	Bus 14-15	-2.0	Bus 25-26	3.9
Bus 4-6	9.3	Bus 16-17	-4.6	Bus 25-27	-1.0
Bus 5-7	-5.9	Bus15-18	-6.3	Bus 28-27	-14.4
Bus 6-7	-28.8	Bus 18-19	-3.0	Bus 27-29	1.7
Bus 6-8	-13.0	Bus19-20	6.4	Bus 27-30	7.1
Bus 6-9	-9.9	Bus 10-20	8.7	Bus 29-30	-3.7
Bus 6-10	4.6	Bus 10-17	4.4	Bus 8-28	5.5
Bus 9-11	-50.1	Bus 10-21	17.3	Bus 6-28	8.9
Bus 9-10	40.2	Bus 10-22	8.6		

Table-4 OPF Result by POWER WORLD

Unit	1	2	3	4	5	6
Pi,max (MW)	360.2	140	100	100	100	100

Pi,min (MW)	0	0	0	0	0	0

Table-5 Unit System – Generator limits (OPF Result by POWER WORLD)

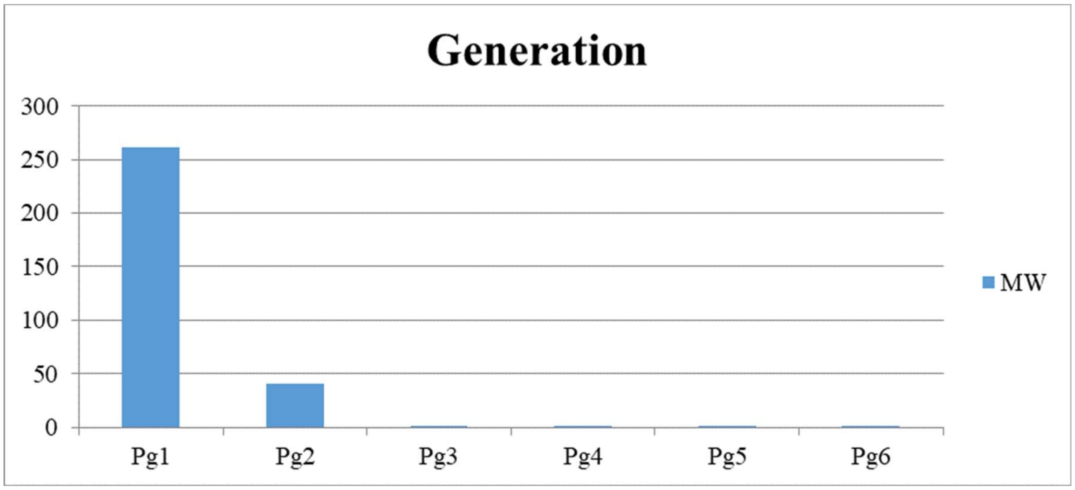

Fig.5- Optimal Scheduling of Generators (MW) (OPF Result by POWER WORLD)

Pg1	Pg2	Pg3	Pg4	Pg5	Pg6
261	40.7	0.7	0.7	0.7	0.7

Table-6 Optimal Scheduling of Generators (MW) (OPF Result by POWER WORLD)

Fuel cost Co efficient of Gen. unit			
Gen. No	ai	bi	ci
1	100	3	0.038
2	100	3	0.25
3	100	3	0.01
4	100	3	0.01
5	100	3	0.01
6	100	3	0.01

Table-7 Fuel cost Co efficient of Gen. Unit

Objective function	Minimum Cost of Generation
Total Generation	304.21MW
Total load	283.69 MW
Total cost	8894.738$/hr
Total loss	20.52MW
Constraints	Generator MW limits, Line MVA limit
Model	Cubic cost model

Table-8 OPF Result by POWER WORLD

V. SIMULATION RESULTS MATPOWER

Line No	Line Flow	Line No	Line Flow	Line No	Line Flow
Bus 1-2	173.31	Bus 4-12	44.19	Bus 21-22	-1.83
Bus 1-3	87.65	Bus 12-13	-0.00	Bus 15-23	5.04
Bus 2-4	43.65	Bus12-14	7.86	Bus 22-24	5.74
Bus 3-4	82.14	Bus 12-15	17.89	Bus 23-24	1.80
Bus 2-5	82.36	Bus 12-16	7.24	Bus 24-25	-1.21
Bus 2-6	60.38	Bus 14-15	1.58	Bus 25-26	3.54
Bus 4-6	72.13	Bus 16-17	3.69	Bus 25-27	-4.76
Bus 5-7	-14.78	Bus15-18	6.02	Bus 28-27	18.07
Bus 6-7	38.13	Bus 18-19	2.78	Bus 27-29	6.19
Bus 6-8	29.56	Bus19-20	-6.73	Bus 27-30	7.09
Bus 6-9	27.72	Bus 10-20	9.03	Bus 29-30	3.70
Bus 6-10	15.84	Bus 10-17	5.33	Bus 8-28	-0.54
Bus 9-11	-0.00	Bus 10-21	15.79	Bus 6-28	18.67
Bus 9-10	27.72	Bus 10-22	7.62		

Fig 6- Power Flow Result by Mat Power

Pg1	Pg2	Pg3	Pg4	Pg5	Pg6
260.96	40.0	0	0	0	0

Objective function	Minimum Cost of Generation
Total Generation	300.96MW
Total load	283.40MW

Total loss	17.557MW
Constraints	Generator MW limits, Line MVA limit

Table-9 Power Flow Result by Mat Power

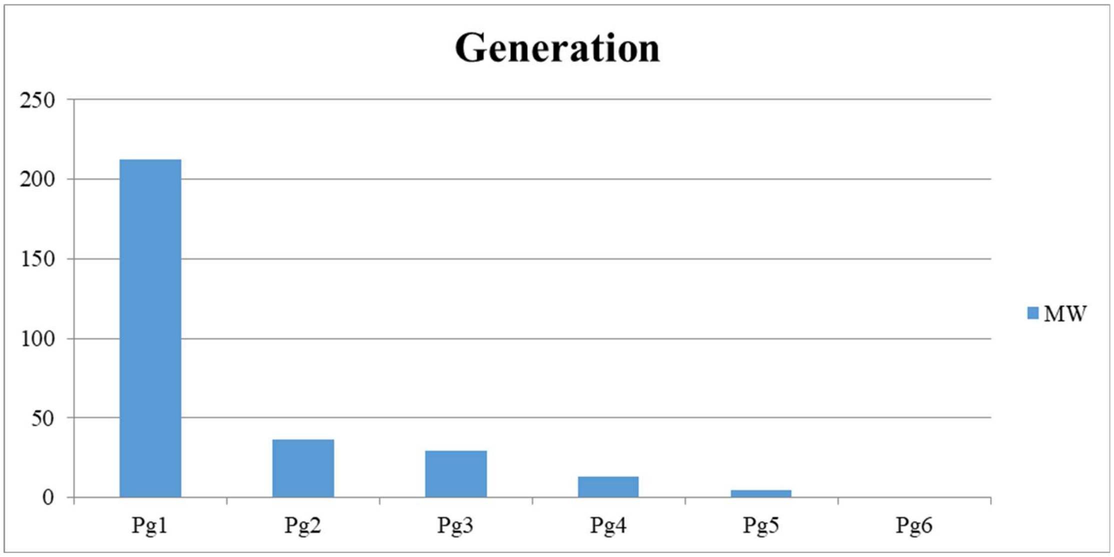

Fig.7 OPF Result by Mat Power

Unit	1	2	3	4	5	6
Pi,max (MW)	360.2	140	100	100	100	100
Pi,min (MW)	0	0	0	0	0	0

Pg1	Pg2	Pg3	Pg4	Pg5	Pg6
212.23	36.23	29.35	12.94	4.40	0

Objective function	Minimum Cost of Generation
Total Generation	295.14MW
Total load	283.40MW
Total cost	8906.14 $/hr.
Total loss	11.74MW

Constraints	Generator MW limits, Line MVA limit

Table-10 OPF Result by Mat Power

Description	Interval1	Interval2	Interval3	Interval4	Interval5	Interval6
Generation (MW)	290.3	293.71	297.09	438.83	303.60	308.20
Load(MW)	283.7	283.7	283.68	283.68	283.6	283.68
Loss(MW)	2.73	2.73	2.72	2.72	2.72	2.72
LMP profit ₹/h	432.09	426.63	386.98	729.17	411.92	298.68

Description	Interval7	Interval8	Interval9	Interval10	Interval11	Interval12
Generation (MW)	289.86	292.93	298.68	300.03	303.60	306.73
Load(MW)	283.68	283.68	283.68	283.69	283.68	283.69
Loss(MW)	2.72	2.72	2.72	2.73	2.72	2.73
LMP profit ₹/h	716.30	866.57	530.34	273.71	411.92	402.97

Table-11Generation and loads of Intervalsby Mat Power

V. CONCLUSION

The penetration of renewable power generation has increased substantially, and is expected to grow in the future. These renewable energy sources are environmentally friendlier compared to the conventional thermal energy sources. Wind and solar energy sources are variable as their electrical power generation varies based on the availability of wind and sun. The load demand is also varies with time, and our power system is designed to handle that variability. A perfect forecast eliminates uncertainty, but there is still variability. Balancing generation and load demand instantaneously and continuously is very difficult task as the loads and generators are fluctuating constantly. As a result of varying wind speed and solar irradiation, wind and solar plants generate varying amounts of electricity. In this paper I have done Matlab analysis for IEEE 30-bus system with Power World Simulator & Mat Power both software.

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