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Evaluation of Economic Impact of Renewable Energy Sources in Multi-period Optimal Operation of Power Systems

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Abstract: In order to operate the electrical network economically and effectively, generation from various sources must be appropriately scheduled. Integrated systems are more common today because of the increase in the cost of fossil fuels and the technological advancements made in the field of renewable energy Resources. To be able to determine the best settings, the optimal power flow problem is posed with all relevant system characteristics, including generator outputs. The network might include conventional fossil fuel generators and renewable energy sources like wind power generators and solar photovoltaic. The classic problem of optimal power flow is a complex non-linear problem with non-linear constraints. In this research, it is suggested how thermal plants with wind and solar integration operate economically using General Algebraic Modeling System (GAMS) software's which has used Non-linear programming to resolve the Dynamic Economic Dispatch (DED) which is a part of optimal power flow problem. The impact of wind and solar integration on the cost-effective operation of thermal units while taking into considering IEEE-24 bus test system has been researched. In this paper, the reduction of a thermal plant's fuel consumption with the integration of wind and solar power is the primary focus of study.
Keywords: Optimal Power flow, Renewable energy resources, Wind and solar power, Dynamic economic dispatch, GAMS.

I. INTRODUCTION

Electric utilities now have to comply with stricter regulations, and modern power systems include numerous interconnections and are built to handle both actual and reactive power demand. This trend has made it imperative to achieve system design and operations with increased security levels and greater sophistication. A lot of research has been done on the "optimum power flow" (OPF) as a potent way to solve this class of operations. The goal of a typical OPF optimization is to dispatch active (P) and/or reactive (Q) power while maintaining the feasibility in considering the power system limits [12]. Deregulation and increased competition have given electric companies new reasons to cut costs. The cost of fuel used to power generator turbines makes up a significant portion of operating costs, hence the electric industry has demonstrated a growing interest in fuel cost reduction. By determining the best distribution of the electric load among the available generation units, a strategy is suggested to reduce these costs. The Economic Load Dispatching (ELD) problem exactly what this is. ELD's primary goal is to save fuel costs while still meeting load demand. However, it's also crucial to be aware of additional factors that, in addition to running costs, can have an impact on critical system characteristics like security and stability. Here, the idea of of optimal flow rises to take care about all those mentioned above. The best active and reactive power dispatch is provided by an optimized power flow solution. It is a non-linear problem with numerous variables with limit constraints of the equality and inequality kind. The operating performance of a power generation-transmission system is optimized using the OPF calculation.

The primary goals of optimal power flow are to:

• Ensure static security and quality of service by placing restrictions on the operation of the generation-transmission system;

• Improve reactive-power/voltage scheduling. To increase operational efficiency by making full use of the system's spectrum of possible operation and by precisely coordinating transmission losses during the scheduling process.

The OPF has traditionally been thought of as the minimizing of an objective function that represents the cost of production. The physical rules regulating the power systems are the limiting factors [6].

Fossil fuels are the main fuel of thermal power, but there is a fear that they will get exhausted eventually with time. So, alternative sources of energy that is the renewable energy sources are very important aspect now-a-days. Renewable energy sources are energy sources that derive their power from the continuous and natural flow of energy that surrounds us. Bioenergy, direct solar energy, geothermal energy, hydropower, wind, and ocean energy are a few of them [9].

Typically, private operators are the owners of wind or solar PV farms. A contract for the purchase of scheduled power from these private operators is signed by the grid operator or independent system operator (ISO) [4,5]. The power output from these renewable resources, however, can occasionally exceed the planned power, which results in an underestimating of the available energy [6]. As surplus power is wasted if it fails to be utilized, ISO will be responsible for the fine.

In this study, the dynamic economic dispatch (DED) solution of thermal generators with wind and solar power integration is taken into consideration. DED stands for the dispatch of generating units over a 24-hour period. The goal of cost-based dynamic economic dispatch is to reduce operational costs while satisfying technological limitations on equality, inequality, and other factors. With regard to equality, inequality, and other technical limitations, generation and demand are matched at each interval of time [2].

The organization of paper as follows : At first, IEEE-24 bus test system consists of ten thermal generating units each with their own cost coefficients, ramp limitations, and maximum and minimum power constraints are considered. Secondly, wind and solar power integrated to test system individually. Finally thermal units with both wind and solar power integration to 24 bus test system is analysed and results are shown.

II. PROBLEM FORMULATION

The objective functions of the problem and its constraints are as follows:

A. Objective Function

The costs associated with producing power using g thermal units over a time period of t, representing the entire cost of electricity generation over a 24-hour period considering thermal units with wind and solar integration as shown in equation below. The objective junction is to minimize the fuel cost of thermal units including wind and solar curtailments.

$$OF=\sum_{i,t} b_g . P_{i,t}^{g} + \sum_{i,t} VOLW . P_{i,t}^{wc} + \sum_{i,t} VOLS . P_{i,t}^{sc} \tag{1}$$

Where b_g, $P_{i,t}^{g}$, $P_{i,t}^{wc}$ and $P_{i,t}^{sc}$ are the fuel cost coefficient of active power generation at unit g, thermal power generation of unit i at time t, wind and solar curtailment in bus i at time t respectively. According to the graph of wind/solar and demand variations, VOLW/VOLS is the cost factor for decreasing the production of wind and solar power in wind and solar power plants by the process known as curtailment occurs when a generator's power production is restricted by order from the power grid operator for ensuring grid stability and system safety.

B. Active and Reactive Power flow Between Buses

The active and reactive power flows in each branch connecting bus i to bus j in the AC network are specified as follows.

$$\mathbf{I_{ij,t}} = \frac{\mathbf{V_{i,t}\angle\delta_{i,t} - V_{j,t}\angle\delta_{j,t}}}{\mathbf{Z_{ij}\angle\theta_{ij}}} + \frac{\mathbf{bV_{i,t}\angle(\delta_{i,t} + \frac{\pi}{2})}}{\mathbf{2}} \tag{2}$$

$$S_{ij,t} = (V_{i,t}\angle\delta_{i,t}).I_{ij,t}^{*} \tag{3}$$

$$P_{ij,t} = \frac{V_{i,t}^{2}}{Z_{ij}}\cos(\theta_{ij}) - \frac{V_{i,t}.V_{j,t}}{Z_{ij}}\cos(\delta_{i,t} - \delta_{j,t} + \theta_{ij}) \tag{4}$$

$$Q_{ij,t} = \frac{V_{i,t}^{2}}{Z_{ij}}\sin(\theta_{ij}) - \frac{V_{i,t}.V_{j,t}}{Z_{ij}}\sin(\delta_{i,t} - \delta_{j,t} + \theta_{ij}) - \frac{b.V_{i,t}^{2}}{2} \tag{5}$$

Where $V_{i,t}, V_{j,t}$ are the voltage magnitudes at the bus i and j (p.u), $Z_{i,j}$ is impedance of transmission line i to j, $\delta_{i,t}, \delta_{j,t}$ *and* $\theta_{i,j}$ are voltage angles at the bus i, j and impedance angle in degree respectively, b is the susceptance of transmission line, $S_{ij,t}$ is complex apparent power flow from bus i to j (MVA) at time t and $I_{ij,t}$ is current flow of branch connecting bus i to j at time t.

C. Power Balance Constraints

The active and reactive power balances in all buses at time t is determined by shown below.

$$P_{i,t}^{g} + P_{i,t}^{w} + P_{i,t}^{s} - P_{i,t}^{L} = \sum_{j\in\Omega_l^i} P_{ij,t} \tag{6}$$

$$Q_{i,t}^{g} - Q_{i,t}^{L} = \sum_{j \in \Omega_l^i} Q_{ij,t} \quad (7)$$

Where $P_{i,t}^{L}$ is the electric demand on bus i at time t , $P_{i,t}^{w}$, $P_{i,t}^{s}$ are wind and solar active power at bus i in time t. $P_{ij,t}$ and $Q_{ij,t}$ are Active power(MW) and reactive power flow (MVAR) from bus i to bus j in time t.

D. Thermal Power Plant Constraints

The following limits are the active and reactive power with complex apparent power maximum and minimum values of thermal power generation plants as well as their ramp-up and ramp-down rate constraints of unit g at bus i in time t, as follows,

$$P_{i,t}^{g,\min} \le P_{i,t}^{g} \le P_{i,t}^{g,\max} \quad (8)$$

$$Q_{i,t}^{g,\min} \le Q_{i,t}^{g} \le Q_{i,t}^{g,\max} \quad (9)$$

$$-S_{ij}^{min} \le \boldsymbol{S_{ij,t}} \le S_{ij}^{max} \quad (10)$$

$$P_{i,t+1}^{g} - P_{i,t}^{g} \le RU_{g} \quad (11)$$

$$P_{i,t-1}^{g} - P_{i,t}^{g} \le RD_{g} \quad (12)$$

E. Constraints related to Renewable Energy Resources

The following are the constraints imposed by wind power plants,

$$P_{i,t}^{wc} = w_t.\Lambda_i^{w} - P_{i,t}^{w} \quad (13)$$

$$0 \le P_{i,t}^{w} \le w_t.\Lambda_i^{w} \quad (14)$$

Similarly, the solar power plant constraints can be defined as,

$$P_{i,t}^{sc} = s_t.\Lambda_i^{s} - P_{i,t}^{s} \quad (15)$$

$$0 \le P_{i,t}^{s} \le s_t.\Lambda_i^{s} \quad (16)$$

Where $P_{i,t}^{s}$, $P_{i,t}^{w}$, $P_{i,t}^{sc}$ and $P_{i,t}^{wc}$ are the solar and wind power integrated also curtailed at bus i in time t, respectively. w_t , s_t , Λ_i^{w} and Λ_i^{s} are wind and solar availability and power plant capacities connected to bus i at time t, respectively.

III. METHODOLOGY

The CONOPT solver in GAMS uses Non-linear programming to solve the Dynamic optimal power flow problem which includes DED[1]. The mathematical models that are developed using the GAMS software have clear algebraic statements and are written in high level language. In order to meet the needs of mathematical modellers, it further combines mathematical programming with relational database theory. Apart from a wide variety of optimization problems, it can handle simultaneous linear and non-linear equation systems and further development would include (linear and non-linear) complementarity problems and general equilibrium problems. The impact of integration of renewable energy sources on the economically feasible operation of thermal units in IEEE-24 bus system has been researched.

The steps in this process as follows:

1) *Sets:* Declaration of number of buses- i ∈{1,2,3..,24}, generating buses, slack bus and time of day- t ∈ {1,2,3..,24} expressed in hours, are referred to as sets for a 24-bus system.
2) *Scalars and Parameters:* Scalar is a fixed quantity at all period t like base values, cost factors using Scalar and renewable capacities using parameters are added in GAMS.

3) *Data:* Data such as cost coefficients, the maximum and minimum output capacities of generators, branch data of 24-bus system, etc. are defined as variables in the form of tables.
4) *Variables:* Variables are unknown values which must be determined and those unknown values like active and reactive powers of thermal generators.
5) *Equations:* Equations related to multi-period dynamic optimal AC power flow, cost function of thermal unit and power balance equation which relates all data elements with sets.
6) *Model and Solver:* The solve statement in GAMS refers to the solver, and the model is the objective function which is used for getting optimum value of objective function.
7) *Output:* Optimal outputs related to objective function , generation values are obtained by using display keyword in GAMS.

IV. CASE DESCRIPTION: IEEE 24-BUS TEST SYSTEM

This section covers the simulations and findings for the IEEE-24 bus system represented in Figure 1 as shown below with power demand on each bus.

Modifications were made to the IEEE 24-bus reliability test system from [1]. Table 1 display the information regarding thermal generating units like cost coefficient, active and reactive power limits with ramp up and ramp down rates. It is the transmission network with voltage levels of 138kv, 230kv and Sbase as 100MVA. Three wind power plants, each with a capacity of 200 MW, 150 MW, and 100 MW are connected to buses 8, 19, and 21, respectively, also one solar power plant with a capacity of 100 MW is connected at bus 3 to make up this power system. Figure 3 displays the daily wind-demand variation patterns and Figure 2 represents 24-hour solar profile pattern versus time. Table 2 displays information from [1] about the network grid, including power line constraints, resistance, reactance, susceptance which are per unit values and also interconnections.

Table 1 : Thermal generation modified data for the 24-bus test system

Generating BUS	P_g^{max} (MW)	P_g^{min} (MW)	b_g ($/MW)	Q_g^{max} (Mvar)	Q_g^{min} (Mvar)	RU (MW/h)	RD (MW/h)
1	152	30.4	13.32	60	-50	21	21
2	152	30.4	13.32	60	-50	21	21
7	300	75	20.7	180	0	43	43
13	591	207	20.93	240	0	31	31
15	215	66.30	21	110	-50	28	28
16	155	54.30	10.52	80	-50	31	31
18	400	100	5.47	200	-50	70	70
21	400	100	5.47	200	-50	70	70
22	300	60	0	96	-60	53	53
23	660	248.4	10.52	310	-125	49	49

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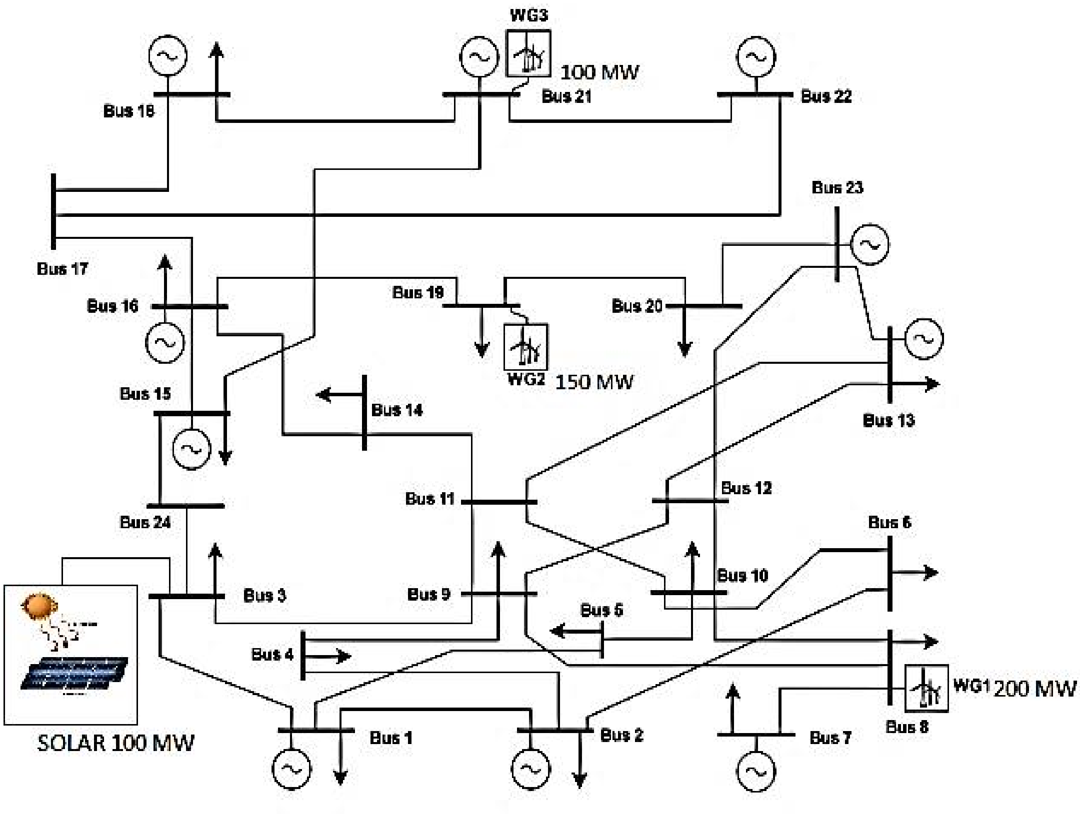

Fig.1: Single Line diagram of IEEE-24 Bus modified Test system

Table 2 : Branch data for the IEEE 24-bus test system.

From	To	r (p.u)	x (p.u)	b (p.u)	Limit
1	2	0.0026	0.0139	0.4611	175
1	3	0.0546	0.2112	0.0572	175
1	5	0.0218	0.0845	0.0229	175
2	4	0.0328	0.1267	0.0343	175
2	6	0.0497	0.192	0.052	175
3	9	0.0308	0.119	0.0322	400
3	24	0.0023	0.0839	0	175
4	9	0.0268	0.1037	0.0281	175
5	10	0.0228	0.0883	0.0239	175
6	10	0.0139	0.0605	2.459	175
7	8	0.0159	0.0614	0.0166	175
8	9	0.0427	0.1651	0.0447	175
8	10	0.0427	0.1651	0.0447	175
9	11	0.0023	0.0839	0	400
9	12	0.0023	0.0839	0	400

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10	11	0.0023	0.0839	0	400
10	12	0.0023	0.0839	0	400
11	13	0.0061	0.0476	0.0999	500
11	14	0.0054	0.0418	0.0879	500
12	13	0.0061	0.0476	0.0999	500
12	23	0.0124	0.0966	0.203	500
13	23	0.0111	0.0865	0.1818	500
14	16	0.005	0.0389	0.0818	500
15	16	0.0022	0.0173	0.0364	500
15	21	0.00315	0.0245	0.206	1000
15	24	0.0067	0.0519	0.1091	500
16	17	0.0033	0.0259	0.0545	500
16	19	0.003	0.0231	0.0485	500
17	18	0.0018	0.0144	0.0303	500
17	22	0.0135	0.1053	0.2212	500
18	21	0.00165	0.01295	0.109	1000
19	20	0.00225	0.0198	0.1666	1000
20	23	0.0014	0.0108	0.091	1000
21	22	0.0087	0.0678	0.1424	500

In branch data, all values of resistance, reactance and susceptance between lines connecting bus i to bus j are considered as per unit values.

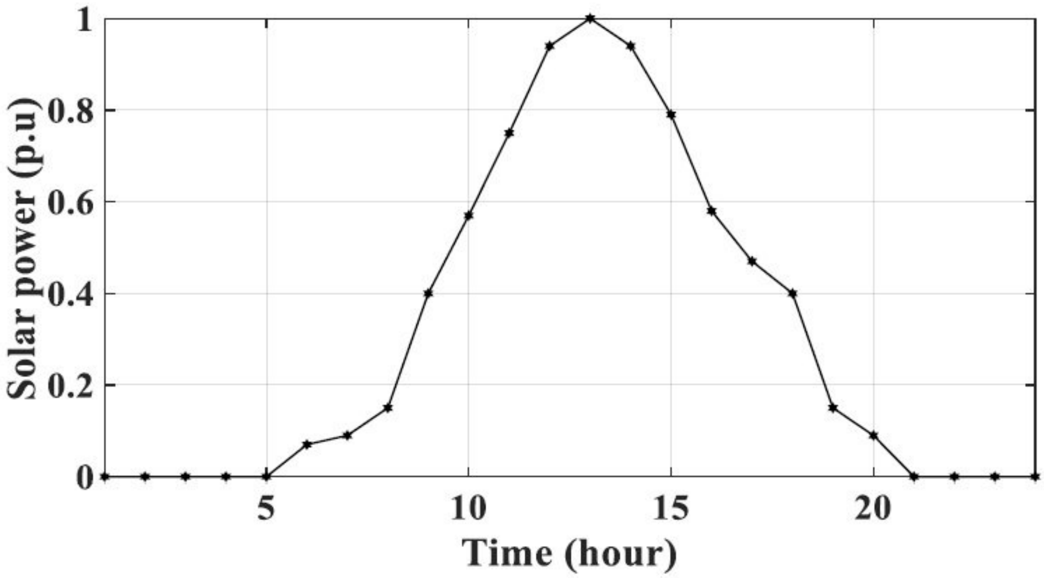

Fig.2 : 24-hour solar power profile pattern vs time

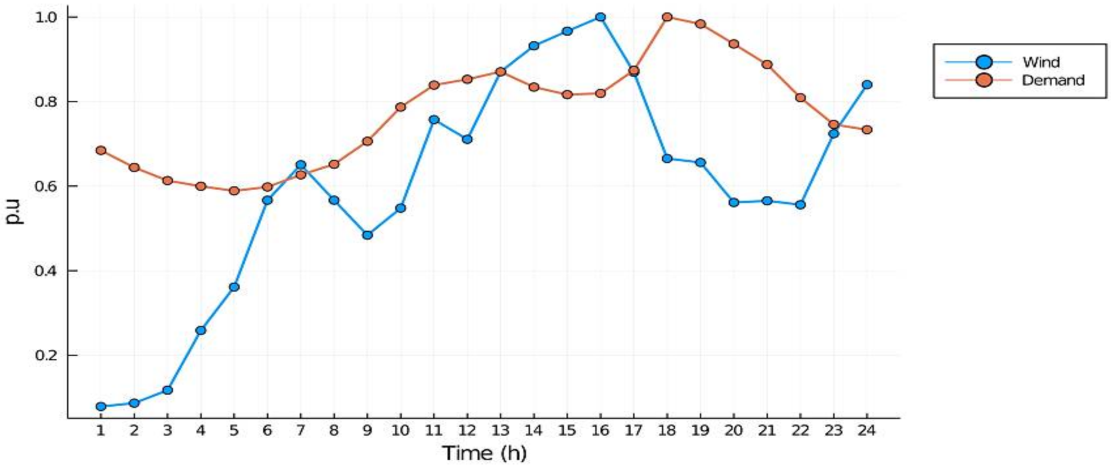

Fig.3 : Wind-demand variation patterns vs. time

V. RESULTS AND DISCUSSION

The Generic Algebraic Modeling System (GAMS) framework is utilized to model this AC optimal power flow problem, and CONOPT is used as an NLP solver to resolve it. Power-Demand balance with Fuel Cost for all cases is tabulated below. Table 3,4,5,6 shows the only thermal units generation, thermal with wind, thermal with solar and thermal with both wind and solar integration of IEEE 24 bus system power generation and demand balance scenario under multi-period AC optimal power flow problem including thermal fuel cost is calculated for 24 hours for all cases. Figure 4 indicates graph of active power generated by all thermal units considering only ten thermal units in IEEE-24 bus system. Similarly, figure 5 and 6 shows active power versus time in 24 hours of thermal and wind integration case.

Table 3: Power-Demand balance with fuel cost variation considering only Thermal units- Case1

Time	Pgt	demand	losses	demand +Loss	thermal fuel cost
Ct1	2001.183	1950.857	50.325	2001.183	17739.660
Ct2	1885.545	1835.750	49.796	1885.545	16423.370
Ct3	1794.117	1747.247	46.870	1794.117	15550.846
Ct4	1753.537	1709.240	44.297	1753.537	15328.871
Ct5	1719.691	1678.291	41.400	1719.691	15242.715
Ct6	1745.391	1704.353	41.038	1745.391	15630.744
Ct7	1830.682	1786.340	44.342	1830.682	16344.734
Ct8	1899.825	1857.468	42.357	1899.825	17338.981
Ct9	2057.631	2012.212	45.419	2057.631	18935.880
Ct10	2293.310	2242.970	50.340	2293.310	21281.770
Ct11	2441.162	2391.198	49.963	2441.162	23218.733
Ct12	2485.719	2430.291	55.428	2485.719	23331.509
Ct13	2538.705	2481.330	57.375	2538.705	23895.502
Ct14	2433.153	2377.624	55.529	2433.153	22667.498
Ct15	2379.665	2327.129	52.536	2379.665	22240.822
Ct16	2378.660	2335.273	43.387	2378.660	23725.557
Ct17	2534.214	2491.103	43.111	2534.214	26879.126
Ct18	2898.214	2850.000	48.214	2898.214	31172.896
Ct19	2851.607	2803.305	48.301	2851.607	30201.620
Ct20	2718.898	2668.651	50.247	2718.898	27665.650
Ct21	2583.563	2529.653	53.910	2583.563	25161.242
Ct22	2361.765	2306.496	55.268	2361.765	21847.649
Ct23	2175.340	2125.691	49.649	2175.340	20094.206
Ct24	2144.034	2090.398	53.636	2144.034	19267.247

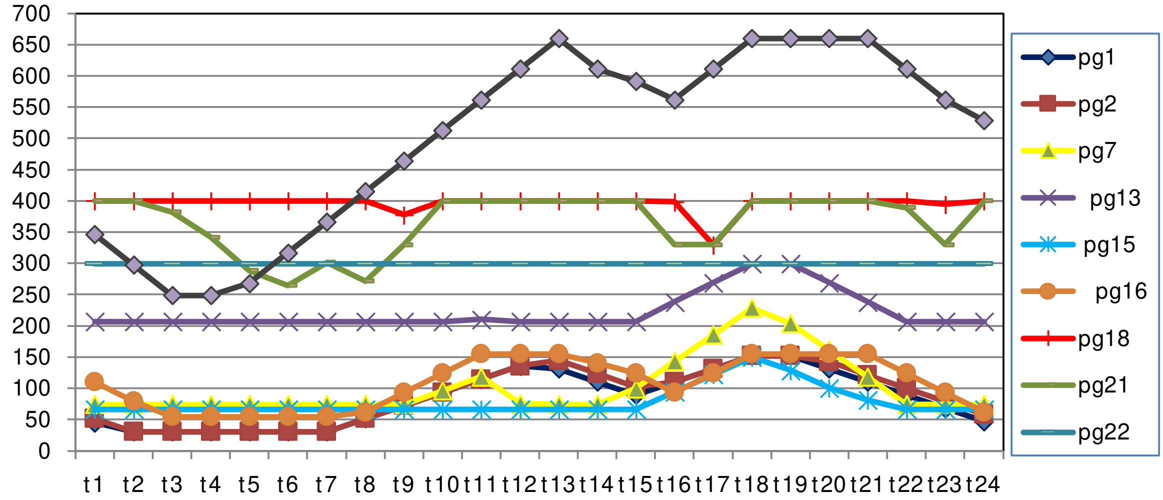

Fig.4: Active power generation of thermal units in MP-ACOPF (Only Thermal units)

P (MW) vs Time (hour)

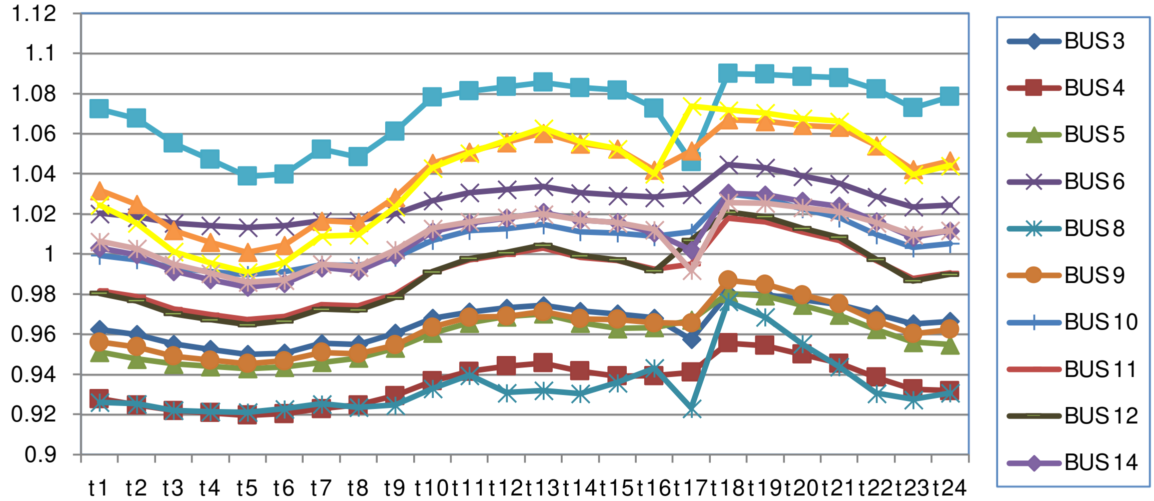

Fig.11: Voltage profile (p.u) at Load buses considering only thermal units

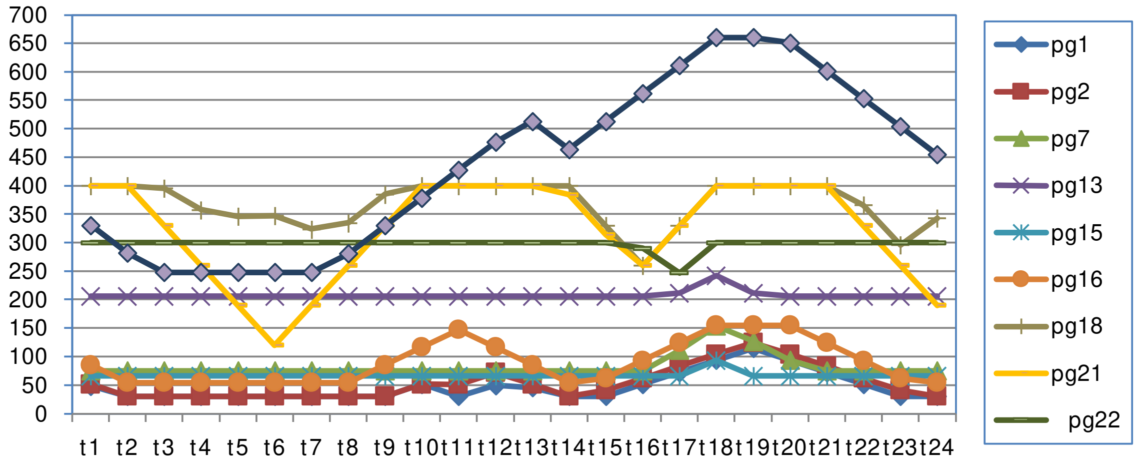

Figure 5: Thermal with wind case2 -Active power generation of thermal units

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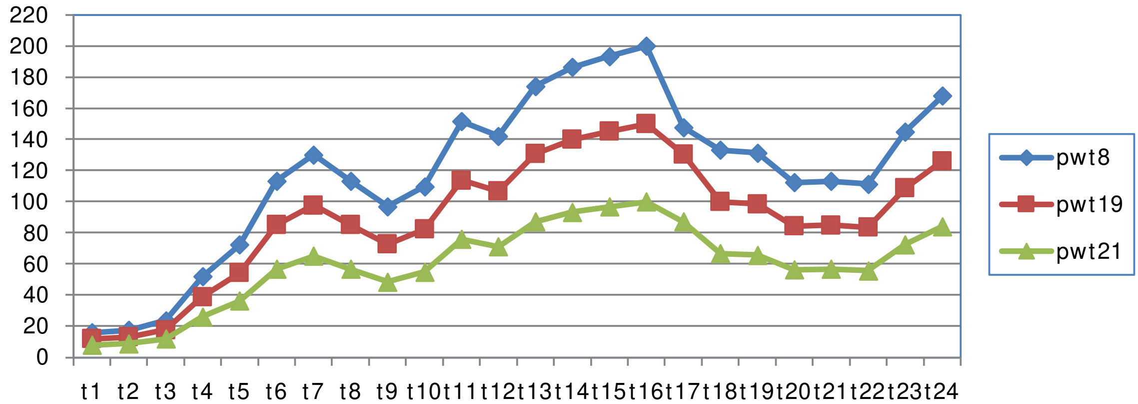

Figure 6 : Thermal with wind case2 Active power (MW) Variation of wind units

Table 4: Power-Demand balance with cost variations considering Thermal units with wind plants integration-Case2

Time	Pgtotal	Pwt	(Pgt+Pwt)	Demand	losses	Demand including losses	Thermal fuel cost	wind Purchase cost
Ct1	1963.938	35.40	1999.338	1950.857	48.480	1999.338	17357.159	1208.945
Ct2	1844.974	39.00	1883.974	1835.750	48.224	1883.974	15996.556	1331.889
Ct3	1737.293	52.80	1790.093	1747.247	42.846	1790.093	15240.019	1803.176
Ct4	1629.283	116.40	1745.683	1709.240	36.443	1745.683	14649.199	3975.176
Ct5	1547.994	162.60	1710.594	1678.291	32.303	1710.594	14204.550	5552.953
Ct6	1479.056	255.00	1734.056	1704.353	29.703	1734.056	13827.460	8708.505
Ct7	1525.794	292.80	1818.594	1786.340	32.254	1818.594	14083.117	9999.413
Ct8	1638.836	255.00	1893.836	1857.468	36.368	1893.836	14864.277	8708.505
Ct9	1838.961	217.80	2056.761	2012.212	44.549	2056.761	16362.961	7438.088
Ct10	2046.041	246.60	2292.641	2242.970	49.671	2292.641	18229.388	8421.637
Ct11	2104.431	340.80	2445.231	2391.198	54.033	2445.231	18783.144	11638.661
Ct12	2162.181	319.80	2481.981	2430.291	51.689	2481.981	19501.964	10921.490
Ct13	2143.436	391.80	2535.236	2481.330	53.907	2535.236	19237.288	13380.362
Ct14	2011.450	419.40	2430.850	2377.624	53.226	2430.850	17828.436	14322.929
Ct15	1938.695	435.00	2373.695	2327.129	46.566	2373.695	17799.573	14855.685
Ct16	1926.542	450.000	2376.542	2335.273	41.268	2376.542	18522.059	15367.95
Ct17	2186.404	364.936	2551.340	2491.103	45.237	2551.340	21553.657	12462.934
Ct18	2603.404	299.40	2902.804	2850.000	52.804	2902.804	25827.427	10224.934
Ct19	2559.178	295.20	2854.378	2803.305	50.073	2854.378	24586.468	10081.375
Ct20	2470.053	252.60	2722.653	2668.651	54.002	2722.653	23144.296	8626.543
Ct21	2329.431	254.40	2583.831	2529.653	54.177	2583.831	21357.768	8688.014
Ct22	2103.576	250.20	2353.776	2306.496	47.279	2353.776	19388.644	8544.580
Ct23	1841.576	325.80	2167.376	2125.691	41.685	2167.376	17221.804	11126.396
Ct24	1751.263	378.00	2129.263	2090.398	38.864	2129.263	16358.680	12909.078

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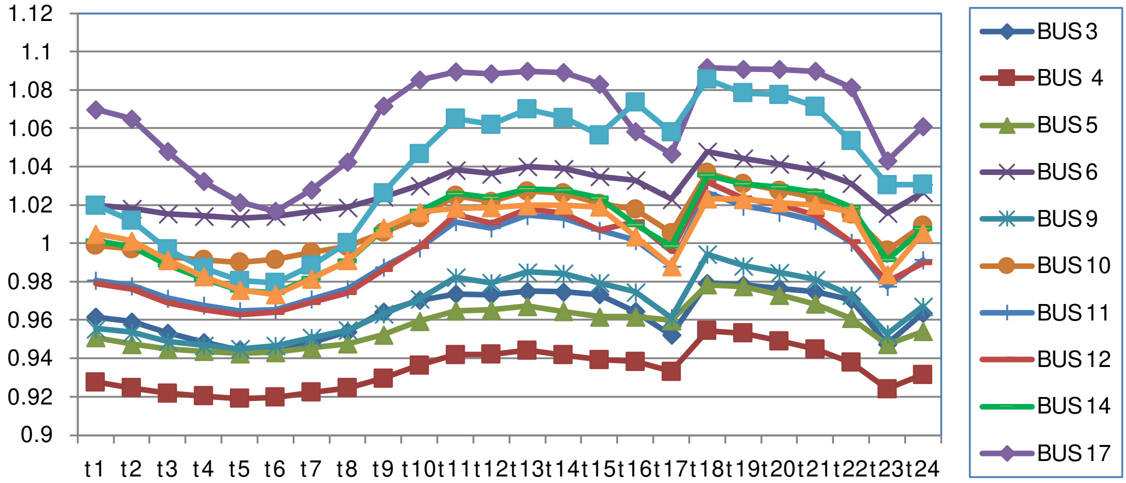

Fig.12: Voltage profile (p.u) at Load buses considering thermal and wind units

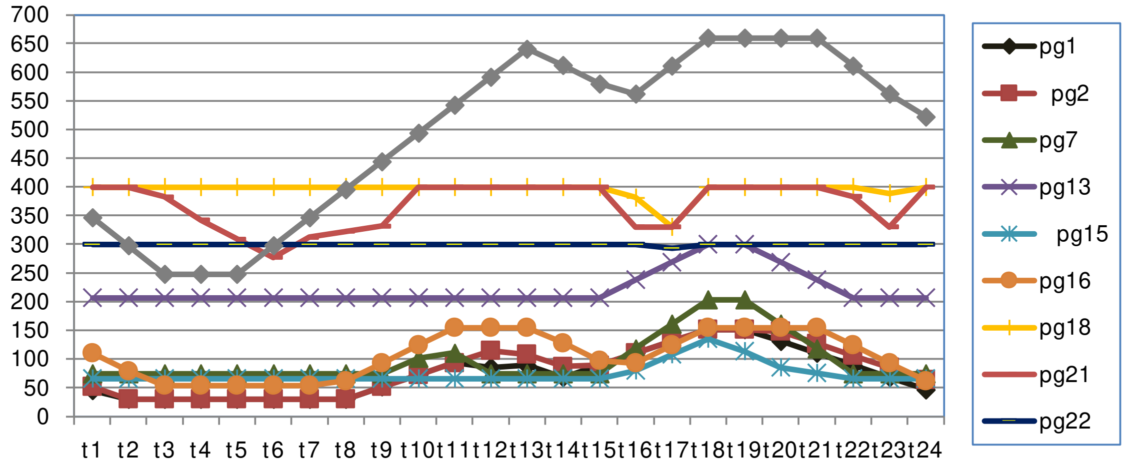

Fig.7: Thermal with solar case3 Active power generation of thermal units

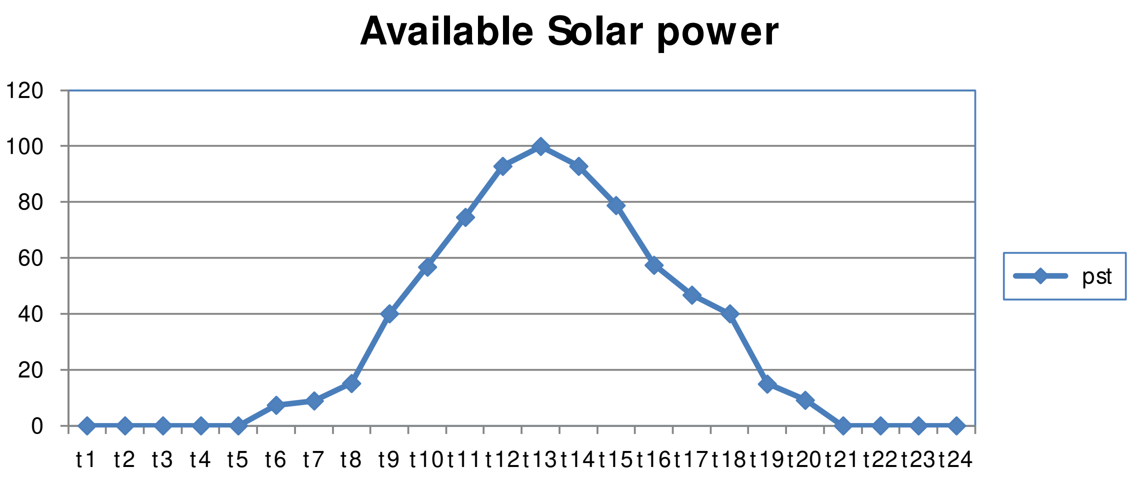

Fig.8 : Thermal with solar case3 Active power (MW) Variation of solar unit

Table 5 : Power-Demand balance with cost variations considering Thermal units with solar plant integration-Case3

Time	pgt	pst	Pgt+ pst	Demand	losses	Demand plus Loss	Thermal fuel cost	solar Pur -chase cost
Ct1	2001.183	0	2001.183	1950.857	50.325	2001.183	17739.660	0
Ct2	1885.545	0	1885.545	1835.750	49.796	1885.545	16423.370	0
Ct3	1794.117	0	1794.117	1747.247	46.870	1794.117	15550.846	0
Ct4	1753.537	0	1753.537	1709.240	44.297	1753.537	15328.871	0
Ct5	1720.566	0	1720.566	1678.291	42.274	1720.566	15148.518	0
Ct6	1738.455	7.276	1745.732	1704.353	41.379	1745.732	15493.825	200.322
Ct7	1821.993	8.891	1830.884	1786.340	44.544	1830.884	16198.223	244.777
Ct8	1889.021	15.174	1904.195	1857.468	46.727	1904.195	16851.206	417.740
Ct9	2020.163	40.000	2060.251	2012.212	48.039	2060.251	18302.730	1101.200
Ct10	2237.203	56.772	2293.975	2242.970	51.004	2293.975	20629.837	1562.933
Ct11	2368.261	74.556	2442.817	2391.198	51.619	2442.817	22218.382	2052.532
Ct12	2394.508	92.889	2487.398	2430.291	57.106	2487.398	22166.887	2557.237
Ct13	2440.572	100.00	2540.572	2481.330	59.242	2540.572	22643.247	2753.000
Ct14	2343.004	92.889	2435.894	2377.624	58.269	2435.894	21499.241	2557.237
Ct15	2303.141	78.846	2381.987	2327.129	54.858	2381.987	21144.640	2170.619
Ct16	2321.575	57.452	2379.027	2335.273	43.754	2379.027	22800.555	1581.648
Ct17	2487.748	46.742	2534.490	2491.103	43.387	2534.490	26047.923	1286.818
Ct18	2858.277	40.000	2898.277	2850.000	48.277	2898.277	30341.693	1101.200
Ct19	2836.122	14.914	2851.036	2803.305	47.731	2851.036	29876.445	410.582
Ct20	2709.111	9.136	2718.248	2668.651	49.596	2718.248	27416.372	251.520
Ct21	2583.203	0	2583.203	2529.653	53.550	2583.203	25109.936	0
Ct22	2361.215	0	2361.215	2306.496	54.719	2361.215	21889.372	0
Ct23	2174.794	0	2174.794	2125.691	49.103	2174.794	20135.945	0
Ct24	2143.568	0	2143.568	2090.398	53.170	2143.568	19278.302	0

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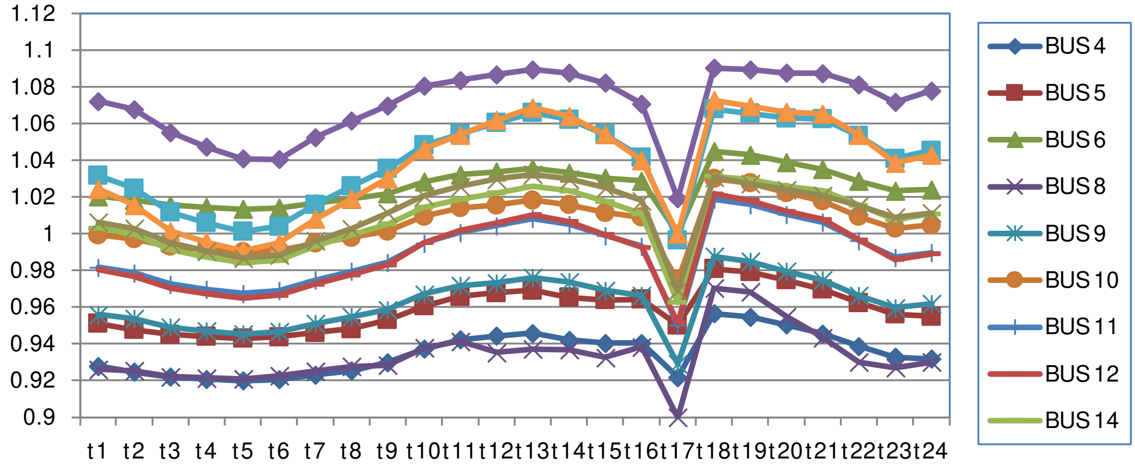

Fig.13: Voltage profile (p.u) at Load buses considering thermal and solar units

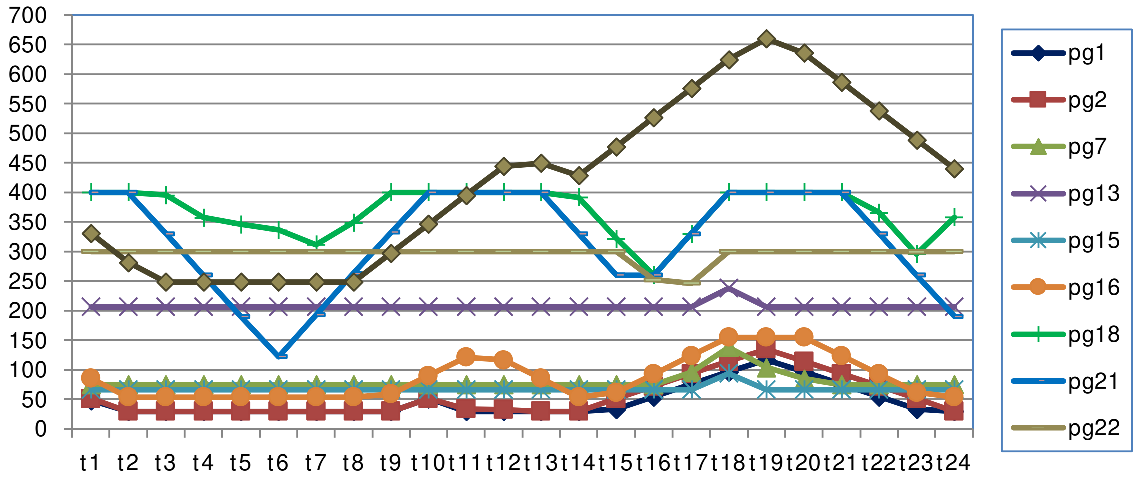

Fig.9: Thermal with both wind and solar case4 Active power generation of thermal units MW vs Time(hours)

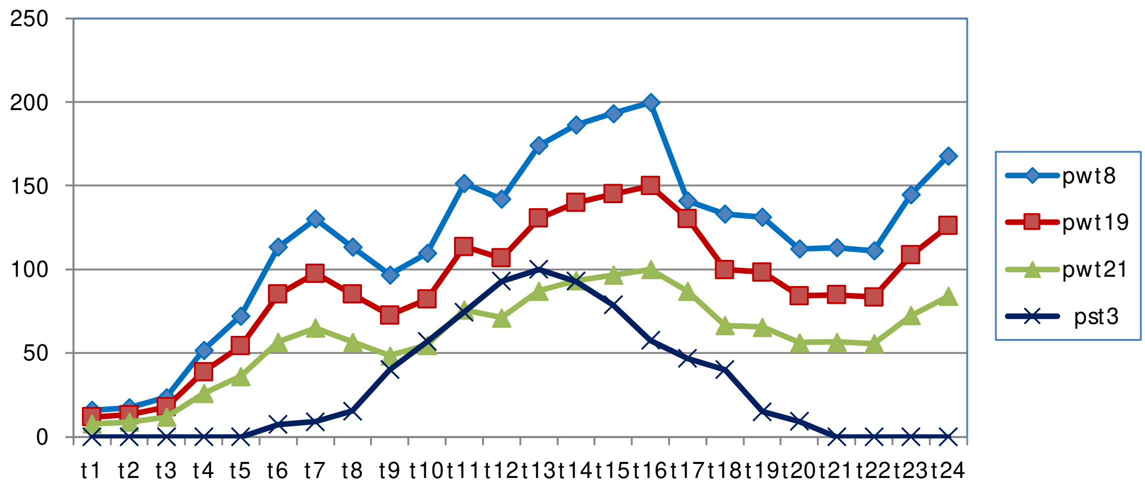

Fig.10: Thermal with both wind and solar case- Pw and Ps (MW) vs Time

Table 6: Power-Demand balance with cost variations considering Thermal units with wind and solar plants-Case4

Time	pgt	pwt	pst	pgt +pwt +pst	Demand	losses	Demand+ Loss
Ct1	1963.938	35.400	0	1999.338	1950.857	48.480	1999.338
Ct2	1844.974	39.000	0	1883.974	1835.750	48.224	1883.974
Ct3	1737.293	52.800	0	1790.093	1747.247	42.846	1790.093
Ct4	1629.283	116.400	0	1745.683	1709.240	36.443	1745.683
Ct5	1547.994	162.600	0	1710.594	1678.291	32.303	1710.594
Ct6	1471.397	255.000	7.276	1733.674	1704.353	29.321	1733.674
Ct7	1516.425	292.800	8.891	1818.117	1786.340	31.776	1818.117
Ct8	1623.955	255.000	15.174	1894.129	1857.468	36.660	1894.129
Ct9	1798.589	217.800	40.000	2056.389	2012.212	44.177	2056.389
Ct10	1987.784	246.600	56.772	2291.156	2242.970	48.185	2291.156
Ct11	2029.350	340.800	74.556	2444.706	2391.198	53.508	2444.706
Ct12	2072.362	319.800	92.889	2485.051	2430.291	54.760	2485.051
Ct13	2044.256	391.800	100.00	2536.056	2481.330	54.727	2536.056
Ct14	1913.796	419.400	92.889	2426.085	2377.624	48.461	2426.085
Ct15	1854.452	435.000	78.846	2368.297	2327.129	41.168	2368.297
Ct16	1867.055	450.000	57.452	2374.507	2335.273	39.233	2374.507
Ct17	2144.619	358.304	46.742	2549.666	2491.103	58.563	2549.666
Ct18	2561.619	299.400	40.000	2901.019	2850.000	51.019	2901.019
Ct19	2544.825	295.200	14.914	2854.939	2803.305	51.633	2854.939
Ct20	2460.362	252.600	9.136	2722.098	2668.651	53.447	2722.098
Ct21	2328.270	254.400	0	2582.670	2529.653	53.016	2582.670
Ct22	2102.402	250.200	0	2352.602	2306.496	46.106	2352.602
Ct23	1840.114	325.800	0	2165.914	2125.691	40.223	2165.914
Ct24	1751.524	378.000	0	2129.524	2090.398	39.126	2129.524

Table 7: Cost variations considering Thermal units with wind and solar plants-Case4

Time	Thermal Fuel cost	wind purchase cost	solar purchase cost
Ct1	17357.159	1208.945	0
Ct2	15996.556	1331.889	0
Ct3	15240.019	1803.173	0
Ct4	14649.199	3975.176	0
Ct5	14204.550	5552.953	0
Ct6	13785.568	8708.505	200.322
Ct7	14031.871	9999.413	244.777
Ct8	14620.055	8708.505	417.740
Ct9	15847.923	7438.088	1101.200
Ct10	17616.517	8421.637	1562.933
Ct11	17946.184	11638.661	2052.532
Ct12	18395.856	10921.490	2557.237
Ct13	18093.011	13380.362	2753.000
Ct14	17116.619	14322.929	2557.237
Ct15	17266.386	14855.685	2170.619
Ct16	18330.611	15367.950	1581.648
Ct17	20926.826	12236.448	1286.818
Ct18	25220.596	10224.809	1101.200
Ct19	24189.336	10081.375	410.582
Ct20	22993.063	8626.543	251.520
Ct21	21383.105	8688.014	0
Ct22	19413.910	8544.580	0
Ct23	17247.070	11126.396	0
Ct24	16286.523	12909.078	0

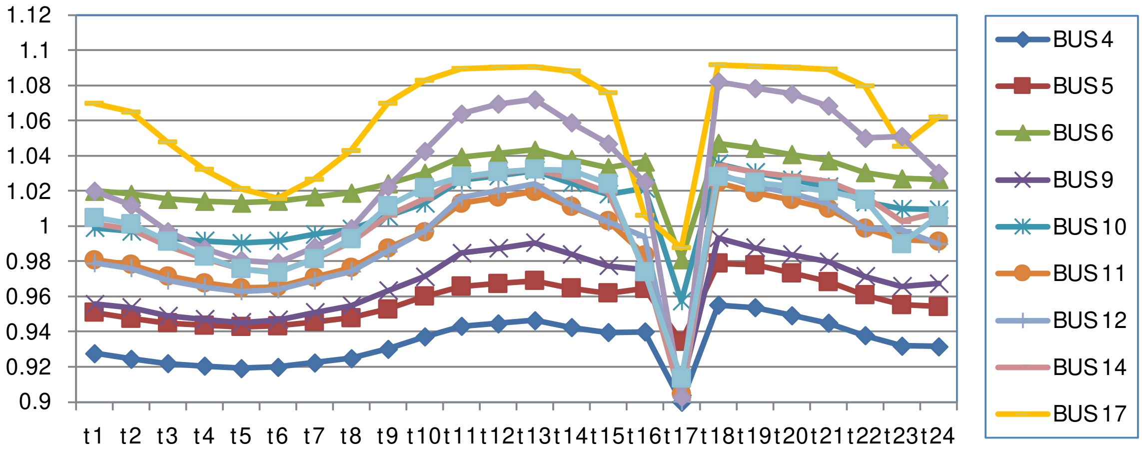

Fig.14: Voltage profile (p.u) at Load buses considering thermal with both wind and solar units

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Table 8 : Results of Cost Optimization for all cases- Comparison

Parameter	Only Thermal units	Thermal+ Wind (3 units)	Thermal+ Solar (1 unit)	Thermal+ Wind+ Solar
Active power loss (MW)	1172.7	1101.7	1189.6	1083.4
Fuel cost ($)	511186.829	435905.894	500236.024	428158.515
Curtail cost($)	-	1313.193	0	1644.788
Overall cost($)	511186.829	437219.087	500236.024	429803.303
Reduction in cost ($)	-	73967.742	10950.805	81383.526
Renewable Purchase cost (wind + solar)($)	-	220299.090 (Wind)	20249.367 (Solar)	220072.604+20249.367 =240321.970 (Wind + Solar)

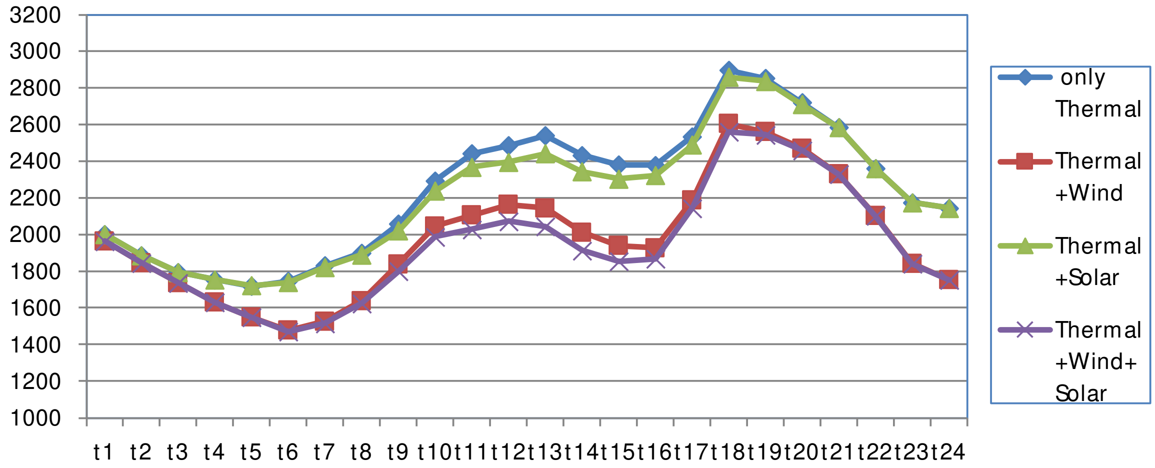

Fig.15: Total Thermal active power generation in all cases

It can be seen that reduction in total active power generation by thermal units in all cases when integration of renewable energy sources like wind and solar is employed to IEEE-24 bus system as shown in figure 15 represents variations in active power generation in 24 hour time period. Renewable purchase costs are calculated by directly multiplying purchase tariffs to how much active power purchased. Table 8 indicates reduction in fuel cost for generating power in thermal power units while considering four cases like presence of only thermal, wind integration with thermal, solar integration with thermal and both wind and solar connected to thermal in IEEE- 24 bus reliability test system. All results are optimal values obtained using CONOPT solver in GAMS.

VI. CONCLUSION

In this research work, lowering the system's generation costs was the ultimate objective. Since fossil fuel reserves are currently running low, it is crucial to reduce fossil fuel consumption, which will also lower the cost of electricity generation by using renewable energy sources in which absence of fuel and its transportation is main advantage. Thus, it can be inferred that the integration of renewables can lower the cost of power generation, which makes the system more affordable by solving the optimal power flow problem taking into consideration all the system constraints.

It is always preferred to rise the system's active power generation when generation costs are reduced. A suitable dynamic multi-objective AC optimal power flow with wind and solar integration to IEEE-24 bus system has been presented out in this study. The CONOPT solver is used in GAMS to solve the multi-period AC optimal power flow problem, which has been described as a non-linear problem. In a 24-hour period, the generators must maintain a balance between generation and load every hour. The 24-hour DED findings and comparison data show the effectiveness of the suggested methodology when all constraints are followed properly. Optimal schedule of thermal plants with wind and solar integration for 24 hours shows the reduction in thermal fuel cost.

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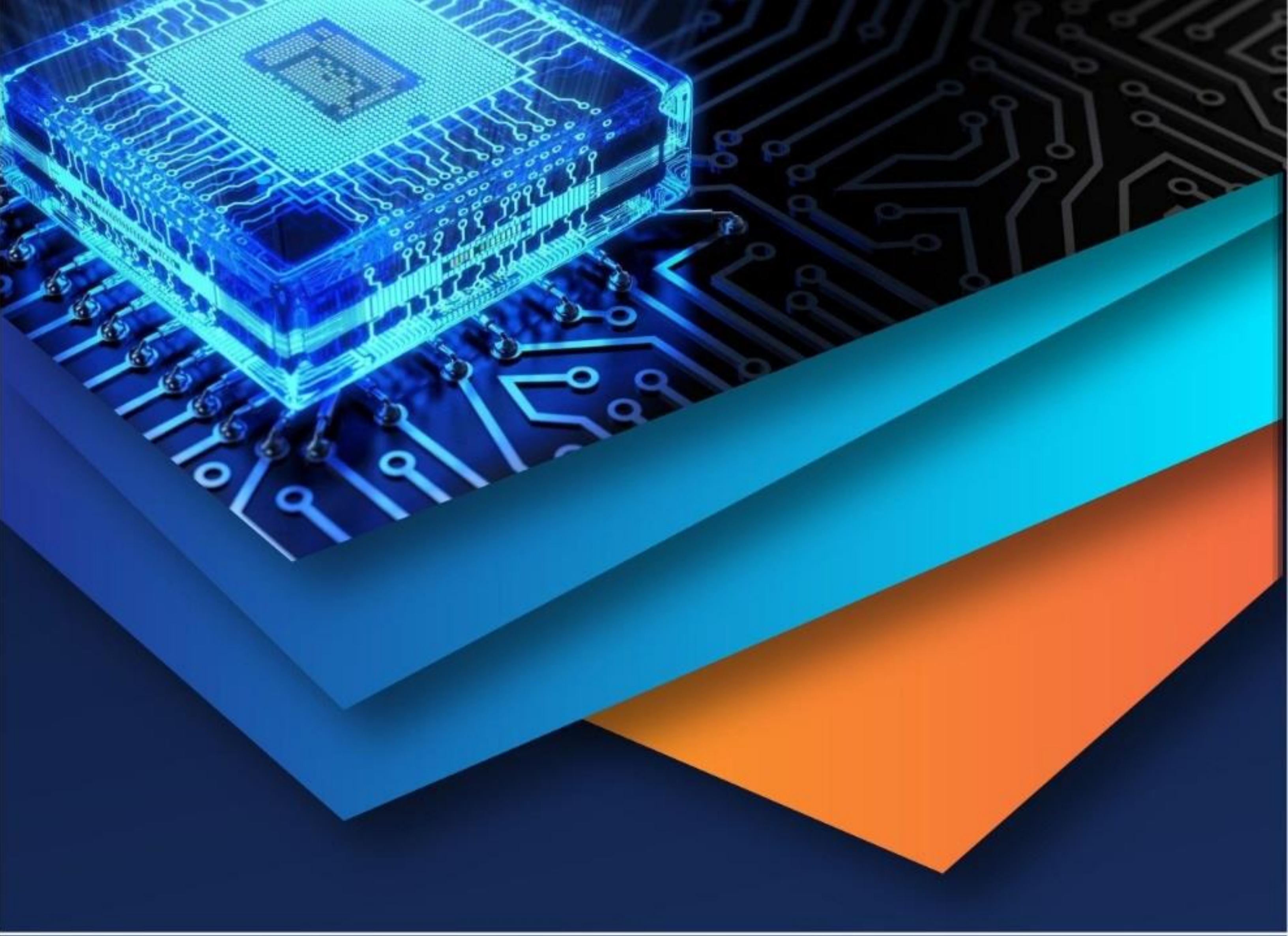

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