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# Optimum Power Flow Analysis For Integration Of Renewable Energy Sources Into Kerala Grid

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**--------------------------------------------------------ABSTRACT--------------------------------------------------------**
*This paper emphasizes on optimal power flow analysis in order to optimize the overall resource utilization while minimizing operating fuel cost, overall active power loss, and adverse environmental effects to satisfy customer's end use requirements. The conventional energy consumption is growing at an alarming rate which leads to many adverse phenomena such as global energy crisis, carbon dioxide emission and global surface mean temperature rise. The main objective is to identify the optimal system scheduling of hydropower plants, thermal plants and wind farms with minimum operating cost and loss with the incorporation of the wind farm in the system. Four different cases such as with and without thermal, with and without wind farm are considered. The most cost effective load scheduling is obtained by renewable integration. The proposed methodology is tested on Kerala grid 220KV– 26 bus system with maximum wind penetration and the results are validated by using simple IEEE 6 bus test system results. The Kerala grid system is proven to be stable and secure in saddle-node bifurcation results using continuous power flow analysis while satisfying all the constraints.*
***KEYWORDS—*** *Optimal Power Flow, Continuous Power Flow, Load Forecasting, Saddle-Node Bifurcation Point, Optimal System Scheduling, maximum loadability*

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## I. INTRODUCTION

Integrated resource planning is the process of optimizing the mixture of resources such as conventional and renewable and minimizes the operating costs while including consideration of environmental concerns. The utilities have to identify a sequence of addition of generation plants which will satisfy the forecasted load at the minimum cost while minimizing adverse environmental effects to satisfy the customer's end use requirements. The use of conventional energy resources is growing at an alarming rate which leads to many adverse global phenomena such as global energy crisis, carbon dioxide emission and global surface mean temperature rise.

The main challenges of power system control engineers are load forecasting and unit commitment. Very long term planning is needed to the installation of power plants. Unit commitment problem is out of available units, which unit will be on or off and how much each unit should be loaded depending on need or depending on some objective function such as the economy, reliability, voltage control and security.

Many studies have been carried out inorder to minimize the cost and loss and to improve voltage profile, reliability and the maximum loadability of the electric loadability of the electric grid. Reference [1] studies the effect of wind integration on minimizing the operating cost and loss. Reference [2] presents a study of the impact of renewable energy sources on operating cost and reliability. Reference [3] investigates the efficient method to optimal power flow to minimize the system losses and operating cost. Reference [4] illustrates a methodology for enhancement of voltage stability margin and thereby winds integration on the large power system. Reference [5] studies the optimal location of RDG using CPF analysis.

Since Kerala is a hydro dominated state, it is insufficient to meet the forecasted load. Considering the huge operating cost of thermal generation, Kerala has been purchased power from central grid throughout the year[6].Because it is less costly than thermal fixed cost and production cost. Usually, the thermal power plants are in offline mode running only at peak times.But price volatality in purchasing power from the center grid is the main issue. The cost of unplanned purchase of power will be several times higher than long-term planning cost. This issue can be overcome by renewable integration and optimum energy management.

In this paper, main objective function to satisfy load is to minimize operating cost with minimum pollution and maximum reliability. If different plants are located at different places, transmission losses cannot be ignored. The research has been conducted by considering four different economic dispatch cases such as with and without thermal and with and without wind farm. The work aims to minimize the cost and loss by maximizing the wind share into the grid. All these simulations have been carried out using the PSAT software version 2.1.10. In conclusion, results of the simulations are compared and analysed.

## II. MARKET MODEL FOR OPF ANALYSIS

### *A. IEEE 06-Market Model*

IEEE06 bus test system model is used for optimal power flow analysis. The results obtained are used for validating the results of the real-time system[7].

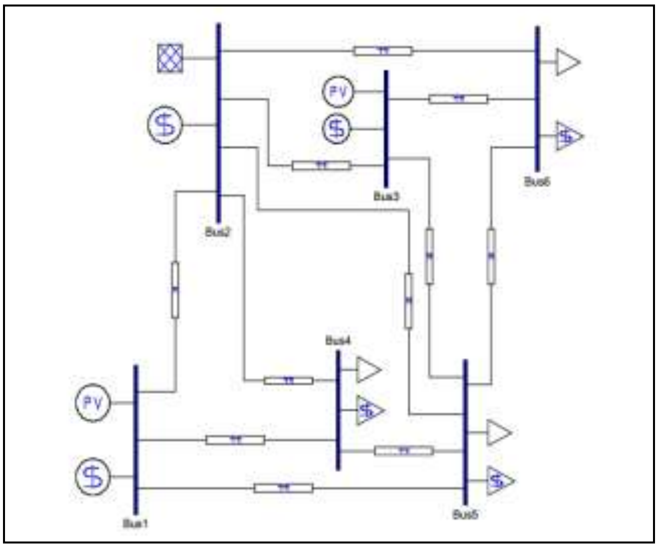


**Fig.1 IEEE-06 bus Test System**

Fig.1 shows the market model of IEEE 06 bus system. The model consists of 3 loads and 3 generators connected to 6 bus system. Here a wind farm is connected to bus –1, bus-2,3 are PV bus and bus-4, 5 and 6 are load buses[8]. Loads were modeled as constant PQ load.

| | |
|---|---|
| **TOTAL LOSSES[MW]** | **12.60** |
| **BID LOSSES[MW]** | **2.72** |
| **TOTAL DEMAND[MW]** | **55** |
| **TOTAL TRANSACTION LEVEL[MW]** | **602.62** |
| **IMO PAY[$/h] without wind integration** | **62.122** |
| **IMO PAY[$/h] with wind integration** | **52.114** |

**Table.I solution statistics of 6 bus test system**

Solution statistics of the test system market model with and without wind integration is shown in table.1.The simulation results show that the operating cost is reduced by renewable integration[9].

### *B. Real System Market Model for OPF*

The Kerala grid 220 KV-26 bus system market model has been modeled with hydro projects at Idukki and Sabarigiry, Lower Periyar and Peringalkuthu, NTPC thermal power plant at Kayamkulam, diesel power plant at Nallalam and wind farms at Agali, Kanjikode and Ramakalmedu[10] including the OPF data. The static model has been used for OPF analysis. The impact of renewable integration in microgrid operating cost and loss has been analyzed by considering four different cases.

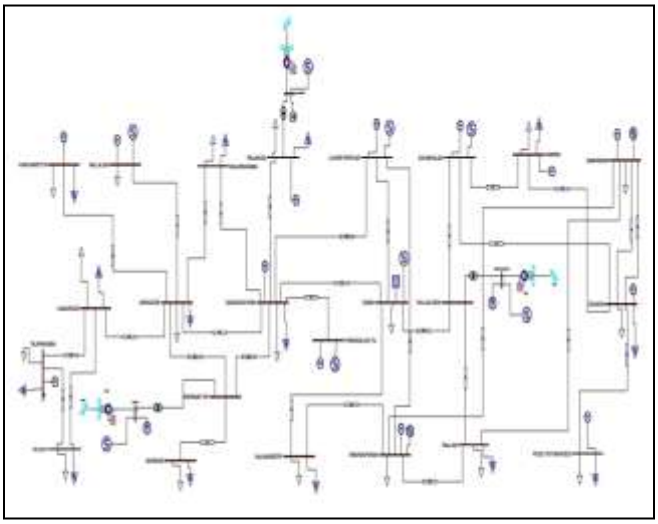

**Fig. 2 Kerala grid 220 KV-26 Bus system [4]**

Fig.2 represents the market model of wind integrated Kerala grid model with 26 buses, 32 transmission lines, 3 transformers, 10 generators and 18 loads[4].

## III. OPF PROBLEM FORMULATION

- The main objective function is to minimize the operating cost of generation and active power loss.
- Equality constraints are power balance at each node.

$P_{Gi} - P_{Li} - P_T(V,\delta)=0$ (1)

$Q_{Gi} - Q_{Li} - Q_T(V,\delta)=0$ (2)

- Inequality constraints are network operating limits such as line flows, voltages, and limits such as active power output of the generating units, the status of switched capacitors and reactors, etc[11].

$Pgimin \leq Pgi \leq Pgimax$ (3)

$Qgimin \leq Qgi \leq Qgimax$ (4)

$V_i min \leq Vi \leq V_i max$ (5)

## IV. RESULTS AND DISCUSSIONS

### *A. Optimal Power Flow Analysis*

The system has been modeled to investigate optimum energy management strategy in four different cases. At first micro grid without renewable integration has been modeled and the system included 23 buses then a renewable integrated market model with maximum wind penetration is modeled with 26 bus system [12]. The four different cases such as with and without thermal plants and with and without wind farms are considered in this study.

| Generator | Cost Coefficients ($/hr) | | | Generation limits | |
|---|---|---|---|---|---|
| | $a_i$ | $b_i$ | $c_i$ | $P_{gmin}$ MW | $P_{gmax}$ MW |
| **THERMAL** | | | | | |
| $T_1$ | 0 | 56 | 1.6 | 10 | 110 |
| $T_2$ | 0 | 52 | 1.2 | 10 | 65 |
| $T_3$ | 0 | 79.2 | 0.001562 | 150 | 600 |
| **HYDRO** | 0 | 3.0 | 0 | | |
| **WIND TURBINE** | 0 | 4.10 | 0 | | |

**Table.II generator cost functions**

Operating fuel cost of thermal generators and feeding cost of hydro and wind turbine generators are taken from the south Indian grid for this study [13]. For the generator having the same rating should not have same fixed cost and running cost when installing at different places.Table.2 gives the generator cost functions of thermal power plants T1, T2, T3 such as Nallalam, Brahmapuram, Kayamkulam respectively and feeding cost of hydro and wind farms.In this study operating cost functions of same generating limits taken from south Indian grid have been considered for the comparative study of different optimum energy management strategy[14]. Fixed costs are omitted from this study for getting more precise results.Table.3 shows the different cases considered in this study[15].

| **Different economic dispatch cases** | **Unit commitment selection** |
|---|---|
| Case 1 | Hydro + Without thermal +Without wind |
| Case 2 | Hydro + With thermal +Without Wind |
| Case 3 | Hydro +Without thermal+ With the wind |
| Case 4 | Hydro +With thermal +With wind |

**Table.III different economic dispatch cases**

Comparative analysis of simulation results of optimal power flow analysis in different cases has been conducted and shown in table.4.The OPF results of case .2 with thermal and without wind share showed a total loss of 23.9 MW and total cost of 249$/hr to meet the total load of 1811.58MW.Whereas reduction in total operating cost and loss is obtained in case 3, the system with wind share showed a total cost of 198$/hr. The loss is reduced to 22.28MW.Total transaction level also has been improved to 1850.25MW.

| **Different Cases** | **Cost ($/Hr)** | **Loss (MW)** | **Total transaction level (MW)** |
|---|---|---|---|
| Case 1 | 225 | 24.8 | 1790.74 |
| Case 2 | 249 | 23.9 | 1811.58 |
| Case 3 | 198 | 22.28 | 1850.25 |
| Case 4 | 222 | 21.38 | 1871.163 |

**Table.IV solution statistics of real-time system in different cases**

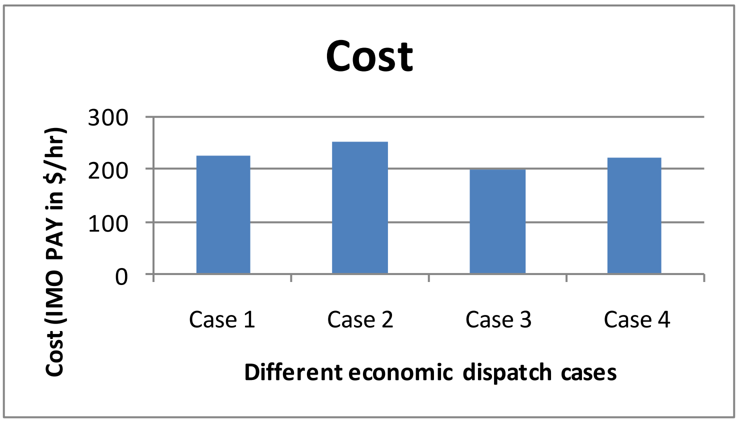


**Fig.3 Comparison of cost in different case**

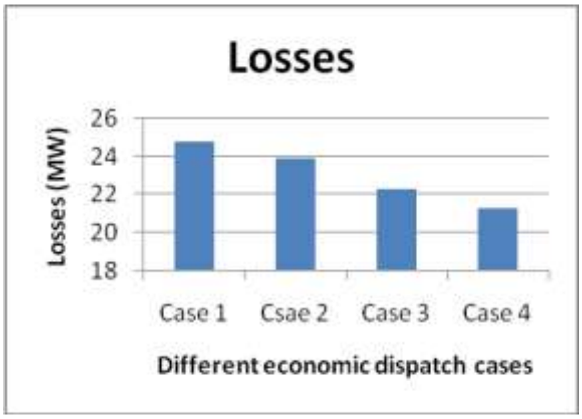


**Fig.4 Comparison of loss in different cases**

The comparison of simulation results in figure 3 and 4 proves that the incorporation of renewables by maximizing wind share and minimizing the thermal power consumption in case 3 will results in savings in production cost and reduction in loss.

***B. Saddle-Node Bifurcation Analysis***

The security and reliability of the system in optimal system scheduling cannot be ignored. Saddle-node bifurcation point will give all information about the reliability of a system[16][17]. In order to prove the system reliability in cost effective case study with renewable integration, saddle-node bifurcation point has been calculated by using continuous power flow analysis.

Figure 5 shows PV curve of the system in case 3 with maximum wind share. Power transfer capability is marked along the X axis and bus voltage in p.u. is marked along the Y axis. The figure shows a stable voltage profile with FACT controller namely SVC and maximum renewable integration. Voltage profile does not reach the bifurcation point or voltage collapse point till the load reaches ten times higher than base load limit($\lambda$ = 10). The capability of the power grid to remain in an acceptable state of equilibrium has been illustrated in figure 5.Also, loading point and maximum transaction level have been improved with renewable integration.

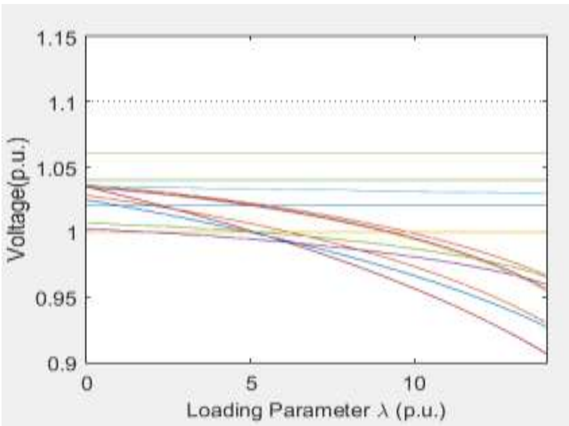


**Fig.5 P-V Curve of Kerala grid system (case 3)**

The saddle-node bifurcation analysis simulation results show no voltage limit violations, all the active and reactive power flows are within the limit,all the apparent power flows are within the limit and current flows are within limit. Voltage profile and phase angle profile in case 3 are shown in figure 5 and 6.

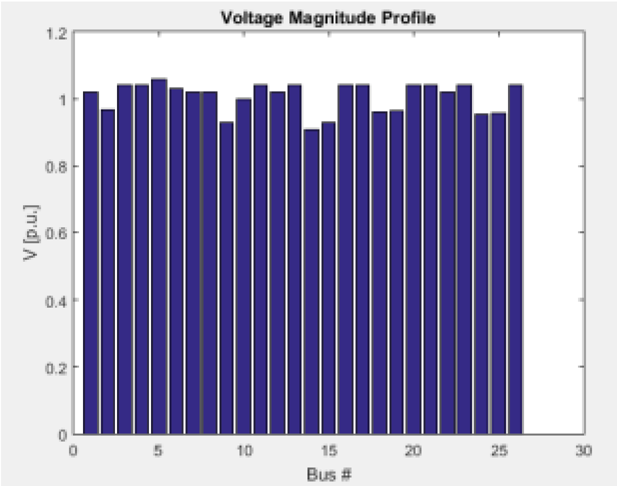


**Fig. 6 Voltage magnitude profile of Kerala Grid system(case 3)**

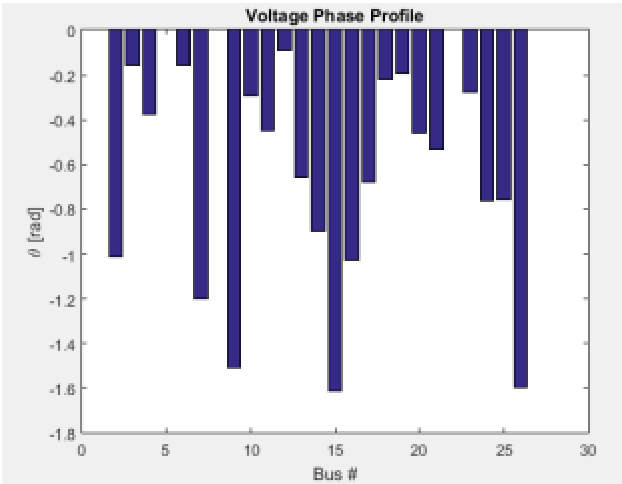


Fig. 6 Voltage phase profile of Kerala Grid system(case 3)

## V. CONCLUSIONS

A comparative analysis of the optimal power flow results by considering Kerala grid 220 KV-26 BUS systems with renewable integration and without renewable integration has been presented in this paper. The ability of optimal system scheduling to minimize the operating cost and overall loss of system has been illustrated in this work. Four different cases are investigated to get best economic dispatch condition. By comparing results, it has been proved that case 3 with hydro and wind farm and without thermal is the best economical scheduling which provides lowest operating cost. Voltage stability, power limits, line powers and system loadability in the practical power system is also maintained within limit which has been proven by continuous power flow analysis. A new methodology for maximizing the wind penetration and savings in production cost by using the optimum energy management and FACTS controller is also presented. The results appear to be quite promising when applied on Kerala grid 220 KV-26 bus practical systems.

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