Maximum Wind Power Penetration

Using LR Technique

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Abstract

This paper deals with the wind penetration of power generating systems. The wind energy shared in the grid is designed as an optimization model which is formulated as a Linear Programming Problem (LPP) with respect to various control parameters in the power system. The objective of this model is to find the maximum load utility period over the time interval. The solution of the model is obtained by Lagrangian Relation (LR) technique. This technique gives the maximum wind shared in the grid using the generated active power output from the wind farms. Based on the numerical calculations and graphical representations, the optimum value is achieved by LR technique. It is compared with the other optimization technique Particle Swarm Optimization (PSO) and the results have been tested through IEEE 14 bus system. The maximum Wind power penetration is used to get the maximum load utility period which leads to the effective power distribution in the electrical system.

Keywords: Lagrangian function, load utility period, wind power penetration, particle swarm optimization, LPP

1 Introduction

For increasing population, the power demand has satisfied by adding wind power to power systems. This wind power generation reducing the operational costs of the power system as less fuel is consumed. The amount of wind power is
increased in the world, particularly in Tamilnadu it has been increased to 6033MW.

Wind power penetration is the economical evaluation of the performance in a interconnected grid system. N. Hatzigiargyriou et al. (2004) have analyzed the security and economic impacts of high wind power penetration in island systems. Estanqueiro et al. (2007) were maximizing the wind penetration by using suitable wind turbines in the wind farms. The studies on wind turbine generators could make by Takam et al. (2009), they proved that Doubly Fed Induction Generator (DFIG) based turbine does not provide any oscillatory instability problems. Weisser et al. (2005) were explained the concepts of instantaneous wind penetration. The maximum wind penetration obtained by using the stochastic model with respect to capacity credit and capacity factor by Milligan et al. (2005) and Voorspools et al. (2006). Kaldellis et al. (2009), Kaldellis (2008) have proposed the new computational algorithm for the calculation of maximum wind energy penetration in autonomous island of Greece. A new method have been proposed for maximum wind penetration by Papathassiou et al. (2006) with respect to constant for load, dynamic penetration limit factor, a grid constant. Wind integration in some high penetration areas are discussed by Hofmann et al. (2007).

In this paper, the maximum wind energy shared in the grid is obtained by Lagrangian function which includes the penalty factor $\lambda$. This Lagrangian multiplier is used for faster convergence.

2 Optimization Model

The LPP model has designed with respect to various parameters and generation operating conditions of the wind power plants.

2.1. Parameters

- $W_p$ – Wind Energy shared in the grid
- $w_f$ – Number of wind farms
- $N_w$ – Total number of wind farms
- $w_t$ – Number of wind turbines
- $N_w$ – Total number of wind turbines
- $N$ – Total number of buses in the system
- $P_D$ – Active power demand at bus $i$
- $Q_D$ – Reactive power demand at bus $i$
- $P_D$ – Total active power demand
- $P_L$ – Total active power loss
- $P_G$ – Active power generation at bus $i$
- $Q_D$ – Reactive power generation at bus $i$
- $MVA_{line}$ – MVA rating of the line
Maximum wind power penetration

\( \text{MVA}_{\text{max}} \) -- Maximum MVA rating of the line
\( K \) -- Total number of existing generators in the grid other than wind
\( V_i \) -- Voltage magnitude at the bus \( i \)
\( V_i^{\text{max}}, V_i^{\text{min}} \) -- Maximum and minimum voltage magnitudes at the bus \( i \)
\( \text{PG}_i^{\text{max}}, \text{PG}_i^{\text{min}} \) -- Maximum and Minimum active power output at the bus \( i \)
\( \text{QG}_i^{\text{max}}, \text{QG}_i^{\text{min}} \) -- Maximum and Minimum reactive power output at the bus \( i \)

2.2. Decision Variable

\( p_{w_i} \) -- Active power output by wind turbines ‘t’ of the wind farms

3 Model Formulation

Objective maximum wind share into the grid.

\[
W_p = \text{Max} \sum_{w_{i=1}}^{N_{w}} \sum_{w_{i=1}}^{N_{w}} P_{w_i}^{w_i} \\
\sum_{j=1}^{N_G} V_j \left( g_{ij} \cos \theta_{ij} + b_{ij} \sin \theta_{ij} \right) = \text{PG}_i - \text{PD}_i, i=1...N_{G} \tag{1}
\]

\[
\sum_{j=1}^{N_L} V_j \left( g_{ij} \sin \theta_{ij} + b_{ij} \cos \theta_{ij} \right) = \text{QG}_i - \text{QD}_i, i=1...N_{L} \tag{2}
\]

\[
\text{PG}_i^{\text{min}} \leq \text{PG}_i \leq \text{PG}_i^{\text{max}} \tag{3}
\]

\[
\text{QG}_i^{\text{min}} \leq \text{QG}_i \leq \text{QG}_i^{\text{max}} \tag{4}
\]

\[
\text{V}_i^{\text{min}} \leq \text{V}_i \leq \text{V}_i^{\text{max}} \tag{5}
\]

\[
\text{PD} + \text{PL} = \sum_{i=1}^{K} \text{PG}_i \leq W_p \tag{6}
\]

\[
\text{MVA}_{\text{line}} \leq \text{MVA}_{\text{max}} \tag{7}
\]

3.1. Proposed Lagrangian Model:

This Lagrangian model is formulated by relaxing the constraint from the LPP model which gives the optimum solution of the optimization model.

Relaxing Equation (7)

Lagrangian Function

\[
L[W_p, \lambda_{\text{MVA}_i}] = \text{Max} \left[ \sum_{w_{i=1}}^{N_{w}} \sum_{w_{i=1}}^{N_{w}} P_{w_i}^{w_i} + \sum_{i=1}^{N} \lambda_{\text{MVA}_i} (\text{MVA}_{\text{line}} - \text{MVA}_{\text{max}}) \right] 
\]

Subject to

\[
\sum_{j=1}^{N_G} V_j \left( g_{ij} \cos \theta_{ij} + b_{ij} \sin \theta_{ij} \right) = \text{PG}_i - \text{PD}_i, i=1...N_{G} \tag{1}
\]
\[ \sum_{i=1}^{NG} V_i (g_i \sin \theta_i + b_i \cos \theta_i) = QG_i - QD_i, i = 1, \ldots, NL \tag{2} \]
\[ PG_i^{\text{min}} \leq PG_i \leq PG_i^{\text{max}} \tag{3} \]
\[ QG_i^{\text{min}} \leq QG_i \leq QG_i^{\text{max}} \tag{4} \]
\[ V_i^{\text{min}} \leq V_i \leq V_i^{\text{max}} \tag{5} \]
\[ PD + PL = \sum_{i=1}^{K} PG_i \leq W_p \tag{6} \]

Lagrangian Relaxation replaces the original problem with an associated Lagrangian problem whose optimal solution provides a bound on the objective function of the problem. This is achieved by eliminating (relaxing one or more) constraints of the original model and adding these constraints, multiplied by an associated Lagrangian multiplier in the objective function.

The main objective of this method is to relax the constraints that will result in a relaxed problem. When it gives the values of multipliers, it is much easier to solve optimally. The role of these multipliers is to derive the Lagrangian problem towards a solution that satisfies the relaxed constraints. The Lagrangian relaxation approach replaces the problem of identifying the optimal values of all the decision variables with one of finding optimal or good values for the Lagrangian multipliers. Most Lagrangian-based heuristics use a search heuristic to identify the optimal multipliers. A major benefit of Lagrangian-based heuristics is that they generate bounds (i.e., lower bounds on minimization problems and upper bounds on maximization problems) on the value of the optimal solution of the original problem. For any set of values for the Lagrangian multipliers, the solution to the Lagrangian model is less than or equal to the solution to the original model. Therefore, the Lagrangian solution is a lower bound on the solution to the original problem. The general application of Lagrangian relaxation can be found in Fisher (1985). An exposition of its use in location models is in the text by Daskin (1995).

In this paper, Lagrangian model gives the optimum solution by relaxing equation with respect to MVA rating of the line in the power transmission system. Objective of this model includes penalty function which gives the optimal solution of the optimization problem.

### 4 Numerical Calculations and Graphical Representations

The proposed model gives the maximum load utility period by using an algorithmic approach which is implemented in MATLAB 7.0. The proposed methodology has been tested on IEEE 14-bus modified test system as shown in Figure 1. The wind farms have been connected to wind bus and the loads have been scaled down to 50% from 100% initially to form the base case. Bus-2 is PV bus and 3, 6, 8 are synchronous compensator buses. Loads were modeled as constant power loads (PQ load) and were solved by using Newton Raphson power flow routine. The load sharing between the wind generators and the system
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generators is through the initial power angle setting. The program was coded in PSAT/MATLAB integrated environment as suggested by Milano F (2005) and was run for 75 iterations. As discussed, the algorithm was implemented in two stages.

From Table 1, the maximum wind penetration 1848.6251 / (MU) (wind energy shared into the grid) obtained by using active power output from the wind farms. Therefore, the maximum load utilized is August in the year 2011-2012 by the wind power plants. Figure 2 gives maximum load utility period for a year by using wind penetration (Wind energy shared in the grid).

Figure 1. IEEE14 bus modified test system

<table>
<thead>
<tr>
<th>Period</th>
<th>W_p using (LR method)</th>
<th>W_p using (PSO method)</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>233.8268</td>
<td>233.7942</td>
</tr>
<tr>
<td>May</td>
<td>533.3464</td>
<td>531.9416</td>
</tr>
<tr>
<td>June</td>
<td>1316.5690</td>
<td>1316.5230</td>
</tr>
<tr>
<td>July</td>
<td>1835.8270</td>
<td>1800.7143</td>
</tr>
<tr>
<td>August</td>
<td>1848.6251</td>
<td>1787.8232</td>
</tr>
<tr>
<td>September</td>
<td>1505.4217</td>
<td>1489.5130</td>
</tr>
<tr>
<td>October</td>
<td>1081.6248</td>
<td>1072.5495</td>
</tr>
<tr>
<td>November</td>
<td>176.4862</td>
<td>173.3142</td>
</tr>
<tr>
<td>December</td>
<td>328.4626</td>
<td>327.6143</td>
</tr>
<tr>
<td>January</td>
<td>309.9757</td>
<td>309.5142</td>
</tr>
<tr>
<td>February</td>
<td>317.5009</td>
<td>315.2331</td>
</tr>
<tr>
<td>March</td>
<td>275.3818</td>
<td>274.4152</td>
</tr>
</tbody>
</table>
Table 2. Maximum $W_p$ for The Month August 2011

<table>
<thead>
<tr>
<th>Period (Hours)</th>
<th>$W_p$ using (LR method)</th>
<th>$W_p$ using (PSO method)</th>
</tr>
</thead>
<tbody>
<tr>
<td>72</td>
<td>143.909</td>
<td>142.980</td>
</tr>
<tr>
<td>144</td>
<td>140.088</td>
<td>140.001</td>
</tr>
<tr>
<td>216</td>
<td>145.421</td>
<td>143.287</td>
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<tr>
<td>288</td>
<td>143.965</td>
<td>141.723</td>
</tr>
<tr>
<td>360</td>
<td>111.592</td>
<td>110.503</td>
</tr>
<tr>
<td>432</td>
<td>76.981</td>
<td>75.825</td>
</tr>
<tr>
<td>504</td>
<td>96.124</td>
<td>94.120</td>
</tr>
<tr>
<td>576</td>
<td>84.677</td>
<td>83.543</td>
</tr>
<tr>
<td>648</td>
<td>97.479</td>
<td>96.335</td>
</tr>
<tr>
<td>720</td>
<td>97.192</td>
<td>96.105</td>
</tr>
</tbody>
</table>

From Table 2, the maximum wind penetration $145.421 / (MU)$ (wind energy shared into the grid) obtained by using active power output from the wind farms. Figure 3 gives maximum load utility period for a month by using wind penetration. Wind energy shared in the grid is optimized by the grid control parameters like voltage, real power, line flow of the power system.
5 Conclusion

The proposed LPP model designed with respect to operational constraints which give the maximum utility period over the planning horizon. Lagrangian function includes the penalty function with respect to the active power output and it gives the optimum solution of the LPP model. The maximum wind penetration obtained by an algorithmic approach by the optimization of grid control parameters. LR technique compared with the other soft computing technique PSO and the results have been tested through IEEE-14 bust system. Based on the numerical calculations and graphical representations, the optimum value is achieved by LR technique. This model determines the maximum wind shared in the grid which leads to the effective power dispatch of the system.

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References


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