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LOAD VARIATION AND WIND POWER INTEGRATION EFFECT IN A PJM 5-BUS BENCHMARK NETWORK FOR POWER SYSTEM ECONOMIC STUDY

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Abstract-*This paper presents a small test framework for power system economic investigations. The framework depends on the PJM 5-bus framework, which contains the information identified with real power just, on the grounds that it shows results based on the linearized DC optimal power flow (OPF) model. This paper recommends some changes to this system, just as new parameters identified with changes in loads and branch line capacity. This paper mainly analyzes the effect of load variation on cost function and how the cost function be minimized by integrating wind power in the existing system.*

Keywords: Power market, energy market, LMP, DCOF

1. INTRODUCTION

Financial examinations, particularly dependent on the locational marginal price (LMP) technique, has turned into a mainstream approach for market-based planning. Here, LMP has been actualized or is under thought at various RTOs or ISOs, for example, PJM, New York ISO, ISO-New England, California ISO, ERCOT, and Midwest ISO. LMP at a given Bus B can be divided into three segments: marginal energy price, marginal congestion price and marginal loss price [1-6].

There is a standard test framework for power system economic studies for the LMP-based market [7]. This paper will use the test framework. The framework is based on the PJM 5-bus system, which contains real power related information only, since it depends on the linearized DC power flow model. Some potential adjustments are recommended just as a couple of new parameters are added to address power flow and cost. This paper recommends some sensible qualities for generation expenses and transmission limits.

Wind power plants often provide a better alternative for supplementing the deficit power requirements of grids as compared to large scale generating units, e.g. hydro and thermal units. Wind power generating units are preferably situated in regions having high potential for wind energy, regardless of their departure from the major load centres in the system.

We have solved a priority order dispatch of generation resources and its locational marginal prices (LMPs) considering a benchmark power system. The suppliers submit the generation selling offer bid constitute of quantities and sale price. The market operators assign the generation share among the units to minimize the generation supply offer cost. The transmission line flow constraints are explicitly considered in the OPF program model.. The LMPs as market-clearing prices at each of the buses of the power system are found by solving the OPF program.

In this paper, the effect of heavy loading on the cost function and power flow is monitored. Then, two wind generator units are consequently added to the existing system and the change in cost function is observed.

2. Methodology

2.1 Problem Formulation

Let consider an electricity market model wherein, a number of competitive generators serving aggregated demand being connected with capacity constrained electricity network. For analytical simplicity, approximated DC power flow model is used. The optimal power flow takes the following form:

$$\min_{x} f(x) \quad (1)$$

Subject to

$$\omega(x) = 0 \quad (2)$$

$$g(x) \leq 0 \quad (3)$$

$$x_{min} \leq x \leq x_{max} \quad (4)$$

In both cases, the objective function f(x) consists of the polynomial cost of generator injections, the equality constraints ω(x) are the power balance equations, the inequality constraints g(x) are the branch flow limits, and the x_{min} and x_{max} bounds include reference bus angles, voltage magnitudes (for AC) and generator injections [9].

2.1 Lagrangian Method

The problem formulation in previous section can be solved by using Lagrangian method. The method does work both for polynomial and piecewise linear marginal cost functions usually practiced for selling offers in electricity markets.The forming of Lagrange function which is presented by Kuhn and Tucker [10].

$$\mathcal{L}(\boldsymbol{x},\lambda,\mu) = f(\mathbf{x}) + \sum_{i=1}^{N\omega}\lambda_i\omega_i(\boldsymbol{x}) + \sum_{i=1}^{Ng}\mu_i g_i(\boldsymbol{x}) \quad (5)$$

The conditions for an optimum for the point x_0, λ_0, μ_0 are

$$\frac{\partial\mathcal{L}}{\partial x_i}(x^0,\lambda^0,\mu^0,) = 0 \quad \text{for } i = 1\ldots..N \quad (6)$$

$$\omega_i\,(x^0) = 0 \quad \text{for } i = 1\ldots..N\omega \quad (7)$$

$$g_i\,(x^0) \leq 0 \quad \text{for } i = 1\ldots..Ng \quad (8)$$

$$\left.\begin{array}{r} \mu_i^0 g_i\,(x^0) \;=\; 0 \\ \mu_i^0 \;\geq 0 \end{array}\right\} \quad \text{for } i = 1\ldots..Ng \quad (9)$$

The first condition is simply the familiar set of partial derivatives of the Lagrange function that must equal 0 at the optimum. The second and third conditions are simply a restatement of the constraint conditions on the problem. The fourth condition often referred to as the complimentary slackness condition, provides a concise mathematical way to handle the problem of binding and nonbinding constraints [11]-[14]. Since the product $\mu_i^0 g_i\,(x^0)$equals to 0, either μ_i^0 equals to 0 or $g_i\,(x^0)$ is equal to 0, or both are equal to 0. If μ_i^0 is equal to 0, g_i (x^0) is free to be nonbinding; if μ_i^0 is positive, then g_i (x^0) must be 0. Thus, we have a clear indication of whether the constraint is binding or not by looking at μ_i^0.

3. PJM 5-BUS SYSTEM

3.1 Original Data from PJM

The PJM 5-bus framework [1] was initially distributed as right on time as 1999. A few refreshed forms have been connected in the next years [15]-[19]. The fundamental framework setup and the proposed generation offers, generation MW cut off points and MW loads are appeared in Fig. 1. More subtleties are displayed straightaway.

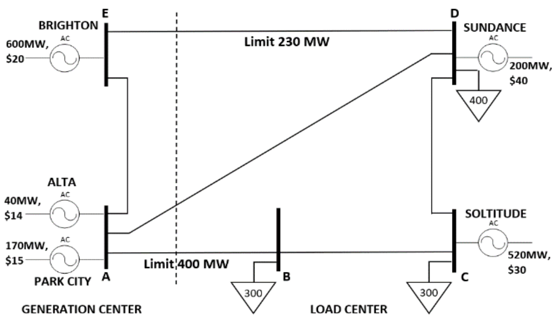

Fig. 1: The PJM 5-bus system

3.2 Suggested Modification

Generation Costs: The PJM online training record arrangement demonstrated a few adjustments to the generation cost and yield of the 5-bus framework in the course of the most recent decade. Essentially, the first information demonstrates a similar generation cost at the Sundance and Solitude buses. This occasionally might befuddle and not direct when instructor or mentors need to clarify the LMP idea. Albeit different variants of various qualities might be connected, here $30/MWh at Solitude and $40/MWh at Sundance are recommended as suitable qualities to separate them.

Generation MW limits: The yield furthest reaches of the Alta unit is diminished from 110 MW to 40 MW, while the yield furthest reaches of the Park City unit is expanded from 100 MW to 170 MW to give adequate contrast when various burdens levels are tried [3-6].

Generation MVAR limits: There is no reactive power limit in the original system. It is suggested that we may use 0.8 power factor from leading to lagging for all units.

Line parameters: The PJM training archive information incorporate penalty factors at each bus under the base case to figure LMP loss part. Be that as it may, there is no depiction about how the punishment elements are determined. For recreation considers, line protections are essential for scientists to "compute" the penalty elements or conveyance factors, particularly for a case altered from the base case [20]-[23]. Past works have expected line protection from be 10% of line reactance. Likewise, here every one of the two shunt capacitances of a "pi"- model transmission line is expected with the end goal that we have a reactance estimation of 10^4 times the line reactance, i.e., 1/(b/2) =10^4 x.

Line flow limits: The first framework demonstrates that solitary the Line DE has a warm point of confinement of 240 MVA. A different line stream limit at Line AB is thought to be 400 MVA. At the point when just genuine power is concerned, we can basically accept 240 and 400 as far as possible, or accept 228 and 380 as MW cut off considering 0.95 power factor connected to all line streams.

Load: The latest forms of the PJM 5-bus framework show 300 MW load at every one of the three burden transports, B, C, and D. It is proposed here to utilize 300 MW, 300 MW and 400 MW for the three burdens to have diverse base-caseloads at various transports. Likewise, a 0.95 slacking force factor is accepted for each transport load.

Voltage limit: Each bus is assumed to have 1.1 per unit as the voltage upper limit and 0.9 as the lower limit. In summary, the complete parameters of the system are listed in Tables 1-3.

Table 1. Generation Parameter

Gen. Name	Alta	Park City	Solitude	Sundance	Brighton
Bus	A	A	C	D	E
Cost($/MWh)	14	15	30	40	10
MW Limit	40	170	520	200	600
MVar Limit	±30	±127.5	±390	±150	±450

Table 2. Load Data

Bus	A	B	C	D	E
MW	0	300	300	400	0
MVar	0	98.61	98.61	131.47	0

Table 3. Line Parameter and Limit

Line	AB	AD	AE	BC	CD	DE
R (%)	0.281	0.304	0.064	0.108	0.297	0.297
X (%)	2.81	3.04	0.64	1.08	2.97	2.97
B/2 (10^{-3})	3.56	3.29	15.63	9.26	3.37	3.37
Limit (MVA)	400	0	0	0	0	240

3.3 Results for Economic Study

The generation dispatch and line flow based on the DCOPF model the modifications are showed in nine following different cases-

Case 1 [Standard test framework]:

Original 5 generation units in individual 5-buses are analyzed shown in fig.1. The loads in bus B, C, D are 300MW, 300MW and 400MW respectively. The total cost function for case 1 is 17552 $/hr.

Case 2 [35% increased load with 5 generators]:

Original 5 generation units in individual 5-buses with 35% increase in loads are analyzed shown in fig.2. The loads in bus B, C, D are 405MW, 405MW and 540MW respectively. The total cost function for case 2 is 29091 $/hr.

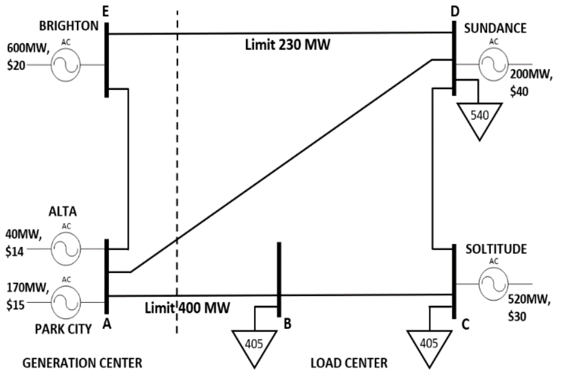

Fig. 2: The PJM 5-bus system with 5 generation units with 35% increased load units.

Case 3 [Heavy load with 5 generators]:

Original 5 generation units in individual 5-buses are analyzed with heavy load of 1400 MW as shown in fig.3. The loads in bus B, C, D are 450MW, 450MW and 500MW respectively. The total cost function for case 3 is 30056 $/hr.

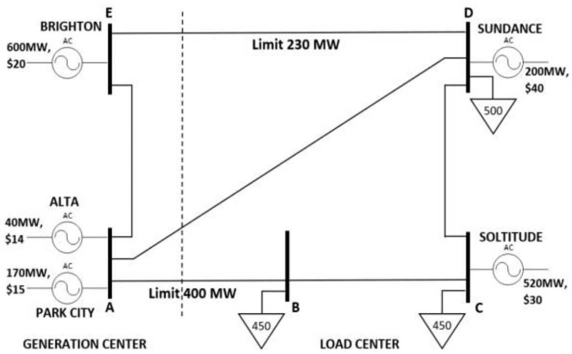

Fig. 3: The PJM 5-bus system with 5generation units and overload (1400 MW).

Case 4 [Rated load with one additional wind generator]:

An additional wind generator unit of 50MW is connected in Bus B as shown in fig.4. The loads in bus B, C, D are 300MW, 300MW and 400MW respectively. The total cost function for case 4 is 17220 $/hr.

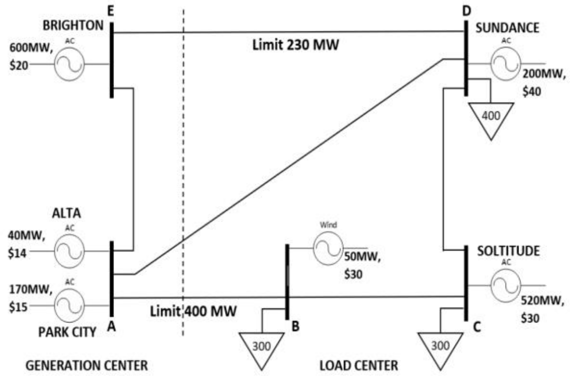

Fig. 4: The PJM 5-bus system with 6 generation units.

Case 5 [35% increased load with one additional wind generator]:

An additional wind generator unit of 50MW is connected in Bus B with a heavy load of 1450MW as shown in fig.5. The loads in bus B, C, D are 405MW, 405MW and 540MW respectively. The total cost function for case 5 is 28752 $/hr.

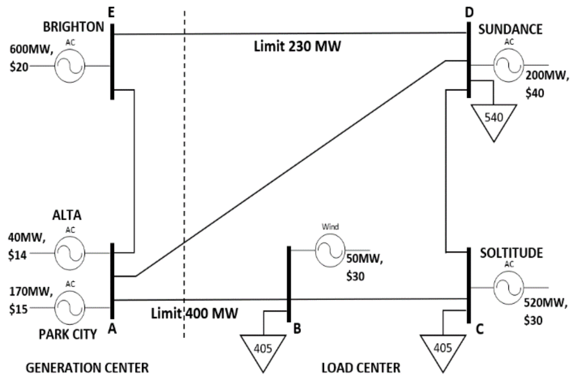

Fig. 5: The PJM 5-bus system with 6 generation units with 35% increased load units.

Case 6 [Heavy load with one additional wind generator]:

An additional generation unit of 50MW as wind generator is connected in Bus B along with the other 5 units are analyzed shown in fig.6. The loads in bus B, C, D are 450MW, 450MW and 500MW respectively. The total cost function for case 6 is 29713 $/hr.

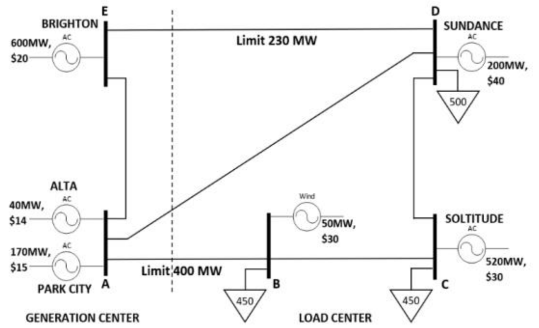

Fig. 6: The PJM 5-bus system with 6 generation units and with overload (1400 MW).

<u>Case 7[Rated load with two additional wind generators]:</u>

Two additional generation units of 50MW each as wind generator are connected in Bus B and C along with the other 5 units are analyzed shown in fig.7. The loads in bus B, C, D are 300MW, 300MW and 400MW respectively. The total cost function for case 7 is 17227 $/hr.

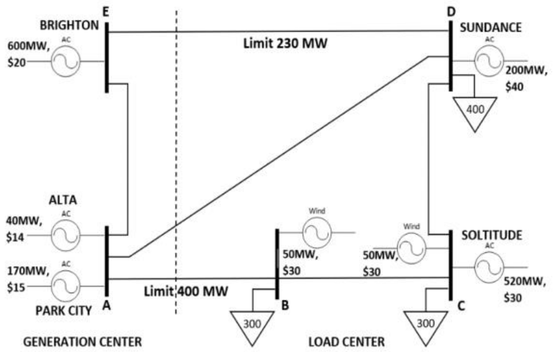

Fig. 7: The PJM 5-bus system with 7 generation units.

<u>Case 8 [35% increased load with two additional wind generators]:</u>

Two additional generation units of 50MW each as wind generator are connected in Bus B and C along with the other 5 units are analyzed shown in fig.8. The loads in bus B, C, D are 405MW, 405MW and 540MW respectively. The total cost function for case 8 is 28775 $/hr.

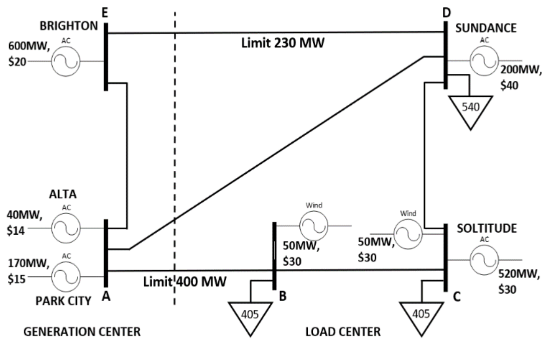

Fig. 8: The PJM 5-bus system with 7 generation units with 35% increased loads units.

<u>Case 9 [Heavy load with one additional wind generators]:</u>

Two additional generation units of 50MW each as wind generator are connected in Bus B and C along with the other 5 units are analyzed shown in fig.8. The loads in bus B, C, D are 450MW, 450MW and 500MW respectively. The total cost function for case 8 is 29712 $/hr.

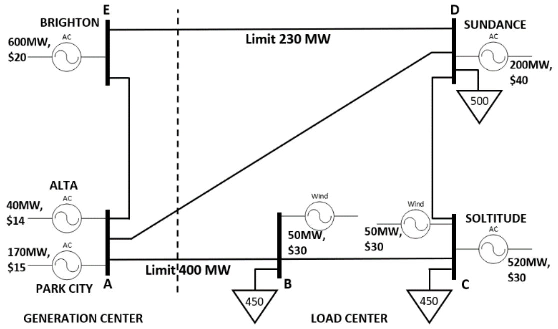

Fig. 9: The PJM 5-bus system with 7 generation units and with overload (1400 MW).

Table 4. Cost for different cases

CASE	No. of Generator	Load	COST($/hr)
1	5	1000	17552
2	5	1350	29091
3	5	1400	30056
4	6	1000	17220
5	6	1350	28752
6	6	1400	29713
7	7	1000	17227
8	7	1350	28755
9	7	1400	29713

Table 5. Branch Power Flow

CS	AB	AD	AE	BC	CD	DE
1	255	187.30	-232.90	-61.02	-24.39	-238.50
2	273	184.16	-247.59	-133.42	-18.81	-238.50
3	316	174.61	-282.95	-136.11	-66.50	-238.50
4	242	189.78	-222.44	-8.88	-26.68	-238.49
5	246	189.09	-225.66	-110.01	4.70	-238.49
6	289	181.54	-261.02	-112.65	-42.94	-238.49
7	243	189.82	-223.16	-8.27	-26.49	-238.47
8	226	192.72	-209.54	-129.61	35.03	-238.47
9	269	185.18	-244.85	-132.27	-12.62	-238.47

The results clearly indicate the variation of cost function with increased load. The main observation that can be made from the results are: The total cost of generation increased with additional load. But the integration of 50 MW wind generator has lowered the cost. Integration of another wind generator does not have any considerable effect on cost function. Therefore, wind generator integration in the bus can result in economic power flow.

9. CONCLUSION

This paper presents a small framework for financial investigation. The framework depends on the PJM 5-transport framework, which was initially gave in PJM's preparation reports. A few adjustments in load information and transmission information are proposed. By changing in load at different buses and incorporation of new loads, several conditions of cost function and branch flow are observed. Also, several cases of load variation and wind power incorporation in the system are evaluated to determine the economic power flow.

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