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MARKET REGULATION BY LMP FLATENNING

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ABSTRACT: The increasing uncertainty on generation and on loads requires the improvement of the sustainability and robustness of the network, which determines the need for new model and applications in several areas, namely in the Transmission Expansion Planning (TEP). This work focuses on a real dynamic TEP model which is based on several planning criteria to reduce the LMP difference. Each criteria is tested on 8 different levels which reduces the potential buses for the installation of new line in between. The results will show the selection of single planning criteria to flatten the locational market price.

Keywords: Average Of Total Congestion Cost(ACC), Locational Market Prices(LMP), Standard Deviation of Mean of Locational Marginal Price(SML), Weighting with Mean of Generation Power(WG), Weighting with Mean of Load(WD), Weighting with Sum of Mean of Generation Power and Load(WGD)

I. INTRODUCTION

According to the European legislation, 'transmission' means the transport of electricity on the extra high-voltage and high-voltage interconnected systems in order to be delivered to final customers or to distributors, but not including supply. The responsibility of this activity is assigned in Europe to TSO's. These entities must ensure the long-term ability of the system to meet reasonable demands and to be accessed by the producers. TSO's are also responsible for the operation, maintenance and development of the facilities, including the interconnections with neighbor systems.

A TEP model aims at determining the timing, the type and the location of the new transmission facilities that should be added to an existing network in order to ensure an adequate transmission capacity taking into account future generation options and load requirements. TEP is important for the regulatory authorities because they need a benchmark, a network planning to serve as reference in the analysis of the plans that are submitted by the TSO´s. In regulated power systems, probabilistic load flow is used to model the random uncertainties in transmission expansion planning. Probabilistic load flow computes PDFs of line flows and bus voltages based on PDFs of loads. In regulated power systems transmission expansion planning is carried out based on the technical criteria such as probability of violation line flow limits and bus voltage limits. In deregulated power systems in addition to the technical criteria, market based criteria are needed to achieve the objectives of transmission expansion planning in deregulated power systems. Therefore, it is needed to compute the PDFs of variables which show the performance of electric market. This work proposes to use PDFs of nodal prices for assessing electric market performance. We used 6 planning criteria's and each criteria is executed in 8 steps, observing the potential buses to which addition of extra lien is to be added to minimise the congestion cost so that LMP becomes flat. Detailed description is given in further chapters

II. PRESENT WORK

The main objective of transmission expansion planning in deregulated power systems is to provide a non-discriminatory competitive environment for all stakeholders, while maintaining power system reliability. To achieve this objective, it is needed to define some criteria to measure how competitive an electric market is and how much a specific expansion plan improves the competition. Te deregulation of market price is observed by locational market price (LMP) criteria. LMPs must be flat in case of regulated market. This is done by minimizing the congestion cost which is defined as:

$$cc_i = (lmp_{i_2} - lmp_{i1})P_{i\,i_1 i_2} \quad i=1,2,\ldots\ldots\ldots\ldots\ldots\ldots N_l$$

with

cc_i congestion cost of line i in \$/hr

N_l number of network lines

Total congestion cost of the network or the opportunity cost of transmitting power though the network is equal to:

$$tcc = \sum_{i=1}^{N_l} (lmp_{i_2} - lmp_{i1}) P_{l\, i_1 i_2}$$

with:

tcc total congestion cost of the network in $/hr

It can be proved that the total congestion cost of the network is equal to the sum of payments by loads minus sum of receives by generators, i.e.:

$$tcc = \sum_{i=1}^{N_b} P_{d_i} lmp_i - \sum_{i=1}^{N_b} P_{g_i} lmp_i$$

with

P_{d_i} load at bus *i* in MW

P_{g_i} generation power at bus *i* in MW

N_b number of network buses

If there is no congestion in the network, the next MW of each load is supplied by the cheapest undispatched generation (marginal generator) and then LMPs of all buses are equal. To minimize the congestion cost various network plan are considered, in our case we have considered 6 plans and each plan is executed 8 times or it can be said that each plan has eight stages. These plans are :

(a) Average of TCC:

Average of the total network congestion cost after addition of plan *k* is equal to:

$$\mu_{tcc}^{k} = \frac{1}{N_r} \sum_{i=1}^{N_l} tcc_j^k$$

with: μ_{tcc}^{k} average of total congestion cost of the network in the presence of plan *k* in $/hr.

(b) Standard Deviation of Mean of Locational Marginal Price

Mean of LMP of each bus is specified with a bar over it. Standard deviation of mean of LMP in the presence of plan *k*, where mean is taken over *Nr* samples and standard deviation is taken over *Nb* buses, is given by

$$\sigma_{\mu_{lmp}}^{k} = \sqrt{\frac{1}{N_b - 1} \sum_{i=1}^{N_b} (\mu_{lmp_i}^{k} - \mu_{lmp}^{k})^2}$$

with:

$\sigma_{\mu_{lmp}}^{k}$ standard deviation of mean of LMP in the presence of plan *k* in $/MWhr

$\mu_{lmp_i}^{k}$ mean of LMP of bus *i* over *Nr* samples in the presence of plan *k* in $/MWhr

μ_{lmp}^{k} mean of $\mu_{lmp_i}^{k}$ over *N*b buses in $/MWhr (average LMP of the network)

(c)Weighting with Mean ofGeneration Power

The mean of generation power at bus *i* after adding plan *k* in the peak load of planning horizon is given by:

$$\mu_{P_{gi}}^{k} = \frac{1}{N_r} \sum_{j=1}^{N} P_{g_{i,j}}^{k}$$

$P_{g_{i,j}}^{k}$ generation power of bus *i* after addition of plan *k* in the *j*th iteration of Monte Carlo simulation in MW

$\mu_{P_{gi}}^{k}$ mean of generation power at bus *i* after adding plan *k* in MW

If weighted standard deviation of mean of LMP with the weight:

$\mu_{P_{gi}}^{k} = w_i^k$ for *i*=1, 2,…, *Nb*

is used as planning criterion, the plan which minimizes the sum of weighted square errors between mean of LMP of generation buses and average LMP of the network (μ_{lmp}^{k}) is selected as the final plan.

(d) Weighting with Mean of Load

The mean of load of bus *i* is given by:

$$\mu_{P_{di}}^{k} = \frac{1}{N_r} \sum_{j=1}^{N} P_{d_{i,j}}^{k}$$

$P_{d_{i,j}}^{k}$ load of bus *i* after addition of plan *k* in the *j*th iteration of Monte Carlo simulation in $\mu_{P_{di}}^{k}$ mean of load at bus *i* after adding plan *k* in MW

If weighted standard deviation of mean of LMP with the weight:

$\mu_{P_{di}}^{k} = w_i^k$

(e) Weighting with Sum of Mean of Generation Power and Load

The mean of sum of generation power and load at bus *i* is given by:

$\mu_{(P_{di}+P_{gi})}^{k} = \frac{1}{N_r}\sum_{j=1}^{N}(P_{d_{i,j}}^{k} + P_{g_{i,j}}^{k})$

$\mu_{(P_{di}+P_{gi})}^{k}$ mean of sum of generation power and load at bus *i* after adding plan *k* in MW

If the weighted standard deviation of mean of LMP with the weight:

$\mu_{(P_{di}+P_{gi})}^{k} = w_i^k$

Complete step by step algorithm for the proposed work is given below:

1. Run the AC power flow to calculate the LMP in the IEEE 30 bus system.
2. Calculate the congestion cost from the LMP using formula explained in equation .
3. Choose one of the six plans discussed above and minimize the congestion cost as per that plan, keeping others fixed and check the behavior of other plans in that case.
4. Execute the program in 8 steps and in each step take out the potential buses where new line will be added in between. In every step of a plan, the potential buses are observed and the number of them should decrease.
5. The mean value to select the potential bus shouldn't be much high and shouldn't be much less otherwise very less buses will be selected in the first case or a large number of buses can be selected in later.
6. Every time the mean value has to check and has to manually intervene the simulation for that purpose.
7. Repeat the steps from 3-6, till all plans are executed and results for them are noted.

III. RESULTS

The proposed work has been implemented in MATLAB and MATPOWER toolbox is used which is freely available online for research work. We have followed the steps described in previous section for IEEE 30 bus test system.

Different Planning criteria propose different paths (expansion plans) to achieve flat price profile or zero congestion cost. To determine the impacts of reduction of one criterion on the other criteria, and to determine which criterion leads to zero congestion cost and flat price profile at minimum cost or at minimum number of expansion plans, transmission expansion planning is performed eight times (stages) under different criteria. For each criterion, after determining the minimax regret plan, it is added to the network and the approach is repeated. At the first stage of planning between each two buses which have average LMP difference greater than SV=$5/MWhr a new line is suggested as transmission candidate. As new lines are added to the network, price profile becomes flatter. Therefore, number of candidates for the next planning stages decreases. In the stages that suggested candidates do not improve the selected criterion or in the stages that only a few candidates are suggested, SV is decreased to have reasonable number of candidates.

For 6 planning stages the simulation is done and results are shown in table 1 to 6 and corresponding comparison graphs are also shown in figure 1 to 6.

IV. FIGURES AND TABLES

Table 1 – Result of planning under SM

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
SML	2.07980	1.54560	1.35420	1.13780	1.0931	0.9276	0.6303	0.4580
WG	1.49770	1.38680	1.23710	1.13020	1.13550	0.5777	0.3732	0.3037
WD	0.92790	0.51620	0.502600	0.367600	0.31270	0.4544	0.3219	0.2862
WGD	1.76180	1.47970	1.33530	1.18850	1.17780	0.7350	0.4928	0.4173
ACC	2.02360	1.70760	1.38100	1.15530	1.14540	0.5293	0.3402	0.2938
ALP	1.22767	1.12801	1.15896	1.21296	1.20810	1.24667	1.23737	1.21426

Table 2 – Result of planning under WG criterion

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
SML	2.7769	2.3987	2.1865	1.5392	1.2539	0.75790	0.37400	0.24470
WG	1.3075	1.0204	0.8467	0.6498	0.6025	0.34390	0.22640	0.09530
WD	1.1659	0.9073	0.8029	0.415	0.6123	0.41200	0.24330	0.12580
WGD	1.7519	1.3655	1.1669	0.771	0.8590	0.53670	0.33230	0.15780
ACC	1.87060	1.1034	0.88890	0.636600	0.47900	0.28680	0.18430	0.16980
ALP	1.15159	1.12505	1.15436	1.128120	1.20296	1.22595	1.21935	1.14523

Table 3 – Result of planning under WD criterion

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
SML	2.1464	1.5620	1.2420	1.1241	1.3774	1.3252	1.4274	1.4006
WG	1.5177	1.3560	1.1318	1.1166	0.61060	0.60990	0.61200	0.60290
WD	0.89420	0.57020	0.43170	0.35080	0.33520	0.23940	0.20360	0.16880
WGD	1.7615	1.4710	1.2113	1.1704	0.69650	0.65520	0.64500	0.62610
ACC	2.0574	1.4151	1.0114	1.0646	0.61300	0.59130	0.63340	0.60130
ALP	1.1685900	1.22485	1.21826	12.143	1.1251	1.11101	1.0816	1.07552

Table 4 – Result of planning under WGD criterion

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
SML	2.7769	2.3987	1.8132	1.4570	1.1188	0.72570	0.38150	0.18820
WG	1.3075	1.0204	0.94040	0.73950	0.49130	0.31070	0.21470	0.078200
WD	1.1659	0.90730	0.65480	0.41790	0.57230	0.38920	0.23560	0.11250
WGD	1.7519	1.3655	1.1459	0.84940	0.75420	0.49800	0.31880	0.13700
ACC	1.8706	1.1034	0.009459	0.72140	0.36590	0.27010	0.18390	0.14260
ALP	1.1515900	1.12505	1.1160	1.1472	1.21863	1.23588	1.21917	1.1424

Table 5 – Result of planning under ACC criterion

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
SML	3.3341	1.7463	1.1200	0.74720	0.41070	0.30880	0.18680	0.13190
WG	1.4272	0.85420	0.64260	0.31230	0.19300	0.15560	0.09930	0.05360
WD	1.3245	0.75250	0.56220	0.37820	0.22030	0.17510	0.10900	0.06820
WGD	1.9471	1.1383	0.85380	0.49050	0.29290	0.23420	0.14750	0.08680
ACC	1.0892	0.67300	0.44960	0.27790	0.18910	0.16810	0.12800	0.09630
ALP	1.19985	1.15891	1.21147	1.19447	1.1698	1.16194	1.15974	1.14747

Table 6 – Result of planning under ALP criterion

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
SML	3.0212	3.3180	3.0446	2.8604	3.0653	3.1446	3.0640	2.7448
WG	1.4681	1.3303	1.2620	1.2988	1.2376	1.4443	1.4396	1.2597
WD	1.1534	1.3741	1.1137	1.2042	1.2310	1.3005	1.2894	1.1566
WGD	1.8670	1.9126	1.6831	1.7711	1.7456	1.9436	1.9326	1.7102
ACC	2.0931	1.8937	1.5129	1.4087	1.4412	1.5537	1.6115	1.4893
ALP	10.8223	9.3490	8.6829	8.5033	8.2369	8.2149	8.0130	7.9563

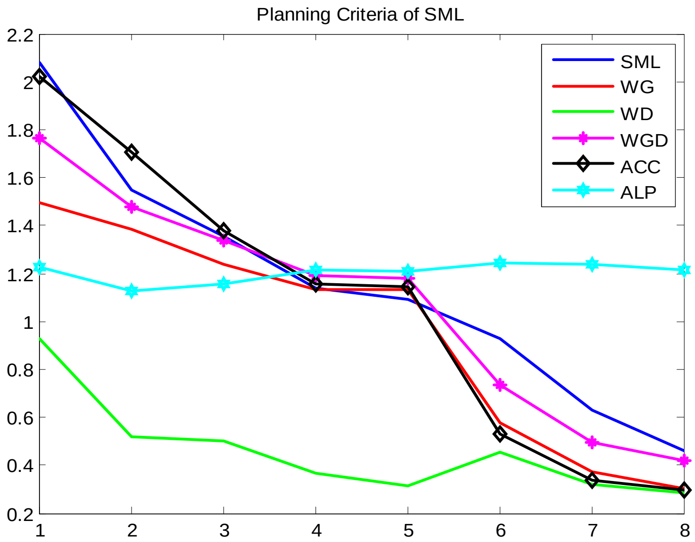

Fig. 1: Values of SML at different stages of planning when SML, WGD, WG, WD, ACC, or ALP is used as planning criterion.

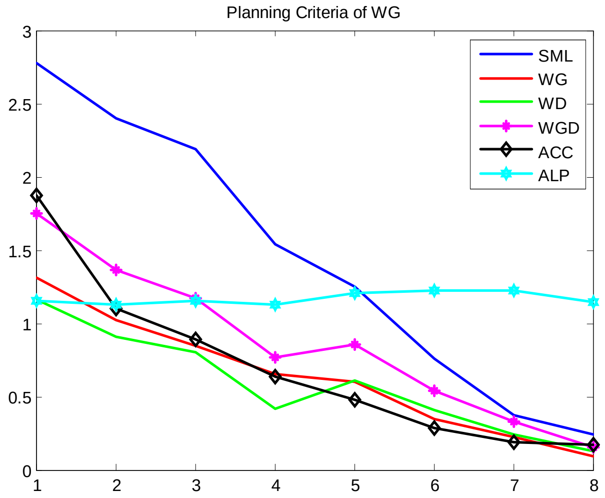

Fig. 2: Values of WG at different stages of planning when SML, WGD, WG, WD, ACC, or ALP is used as planning criterion.

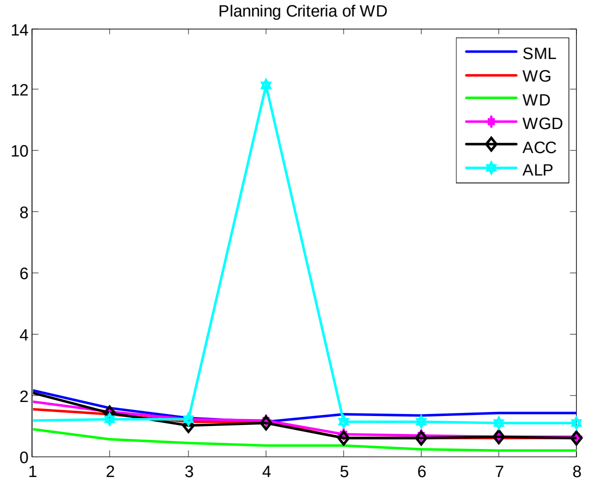

Fig. 3: Values of WD at different stages of planning when SML, WGD, WG, WD, ACC, or ALP is used as planning criterion

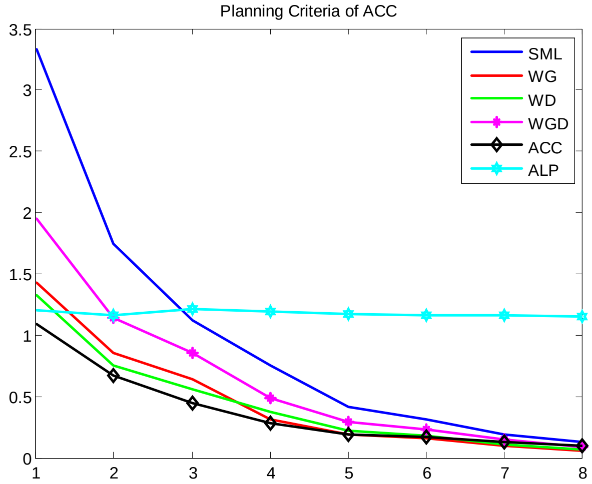

Fig. 4: Values of ACC at different stages of planning when SML, WGD, WG, WD, ACC, or ALP is used as planning criterion

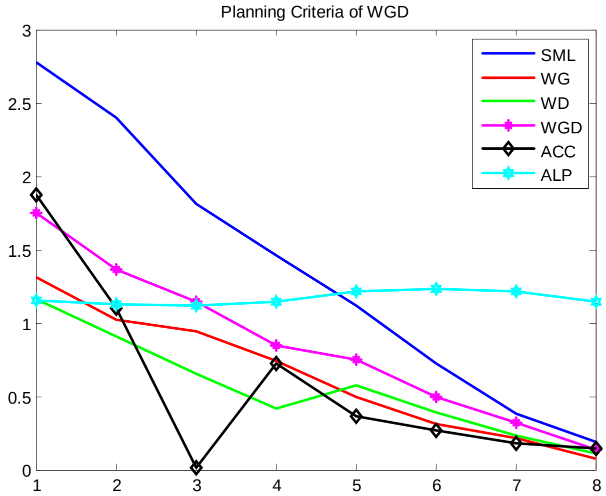

Fig. 5: Values of WGD at different stages of planning when SML, WGD, WG, WD, ACC, or ALP is used as planning criterion

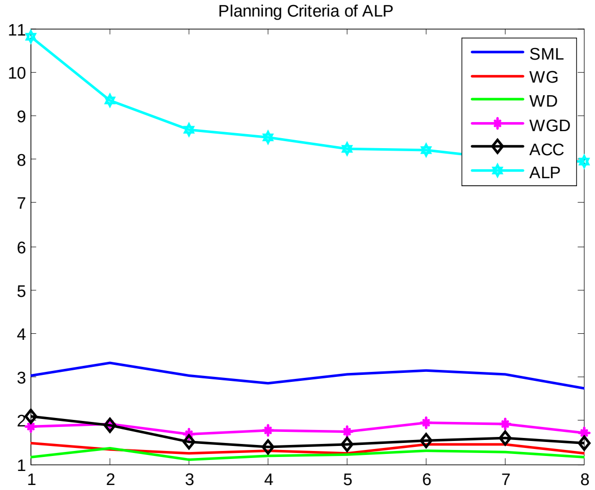

Fig. 6: Values of ALP at different stages of planning when SML, WGD, WG, WD, ACC, or ALP is used a planning criterion

V. CONCLUSIONS

In our work the approach for transmission expansion planning in deregulated power system is presented. On the basis of probability distribution function of locational marginal price, congestion cost has been minimized so that all market players are regularized. We have considered the six plans and each plan is executed for 8 times and each time number of potential buses are analyzed. To determine which criterion leads to zero congestion cost and flat price profile at minimum cost or at minimum number of expansion plans, the presented

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