Improved Zonal Network Models in Generation Scheduling

Kenneth Van den Bergh, Erik Delarue, William D’haeseleer
Energy Institute, University of Leuven (KU Leuven)
Leuven, Belgium
kenneth.vandenbergh@kuleuven.be

Abstract—Realistic generation scheduling models should take account of the electricity grid constraints. Nodal network models describe the grid in detail but require a high granularity of input data and result in long simulation times. Zonal network models are simplified versions of nodal network models, with lower granularity of input data and shorter simulation times, but less accurate simulation results. Detailed nodal network models are not suited for large scale generation scheduling models due to their complexity. Therefore, it is of importance for generation scheduling models to use an appropriate zonal network model, finding a balance between correctness and convenience. This paper compares a nodal network model with a “simple” zonal network model, a zonal network model with higher granularity and a zonal network model with different Power Transfer Distribution Factors for different types of grid injections. This latter zonal network model takes a sufficiently accurate representation of the grid flows, without increasing the simulation time or the granularity of the input data. All discussed concepts are applied to a case study of the Continental European power system.

Keywords—Zonal Network Model; Nodal Network Model; Power Transfer Distribution Factors

I. INTRODUCTION

Electricity grids constrain the scheduling of power plants. The optimal generation scheduling is subject to limited transmission capacity between the different generating units and loads. The power flows through the grid are determined by the physical laws of electricity and are such that a single transmission constraint might influence all the flows in the grid. Therefore, it is essential to include – at least to a certain extent – grid constraints in generation scheduling models. The term generation scheduling model refers to models which determine the optimal dispatch of a set of generating units in order to meet a certain load, taking account of technical and cost-related constraints. Generation scheduling models are being used by, amongst others, generation companies and system operators. Generation scheduling models often use a DC load flow approximation of the grid. According to the DC load flow assumptions\(^1\), the network model is translated in Power Transfer Distribution Factors (PTDF) which describe a linear relationship between the injections in the grid and power flows through the grid [1].

One distinguishes two different types of network models that can be used in generation scheduling models; nodal network models and zonal network models. In nodal models, each – relevant – node and line is included in the network model. In zonal network models, different nodes are grouped into zones, represented by equivalent nodes. Similarly, transmission lines between zones are aggregated to equivalent inter-zonal links while intra-zonal lines are omitted from the model\(^2\). Obviously, reducing nodal models to zonal models goes together with a loss in accuracy of the grid representation. The advantage of zonal network models is the relative simplicity, in the sense that fewer grid constraints have to be taken into account and system data only have to be known on an aggregated level (e.g., installed generation capacity has to be allocated to zones instead of nodes). This in turn makes the computational issues (e.g., computation time) more tractable. In short, the difference between nodal and zonal network models comes down to finding a balance between accuracy (i.e., taking account of all grid properties) and convenience (i.e., usefulness of the network model in real-life applications). In the literature, a lively and extensive discussion on this matter can be found (see for example [2]).

Two different viewpoints with regard to the nodal-zonal discussion can be found in the literature. The first one is the pure economics approach, discussing zonal and nodal network models in terms of differences in system costs and economic welfare. The second viewpoint is the engineering approach, comparing zonal and nodal network models based on differences in power flows and zonal generation balances. Economists focus on the impact of nodal-zonal network models on generation costs. According to the economist’s approach, a nodal network system is more economically efficient and internally consistent than a zonal network system [3]. This can be understood as follows; a generation scheduling model with a nodal network model finds an

\(^1\) A DC load flow analysis is a linearization of an AC load flow analysis, based on the assumptions of lossless lines, a flat voltage profile and small voltage angles between neighboring nodes.

\(^2\) Nodal and zonal are relative concepts rather than absolute concepts, depending on the scope of the analysis. For example, in a European grid study, a nodal network model might include all nodes and transmission lines above 200 kV while a in a zonal network model each country can be represented by one equivalent node. On the other hand, in a Belgian grid study a nodal model might cover all voltage levels while the zonal model is limited to voltage levels above 200 kV.
The paper approaches the nodal-zonal debate from the engineering point of view. In the scope of generation scheduling models, nodal network models are not suited for large scale simulations due to their complexity. Therefore, accurate zonal network models are needed. This paper compares a nodal network model with three different zonal network models: a “simple” network model with only 10 zones, an improved zonal network model with 31 zones and another improved zonal network model with 10 zones but with different PTDFs are used for different types of grid injections. It turns out that the latter zonal network model outperforms the other zonal models in terms of accuracy. The different concepts presented in this paper are applied to a case study of the Central European power system. Simulations are performed with a detailed unit commitment model.

The paper is structured as followed. Section II describes the methodology, consisting of the case study description, a theoretical overview of network reduction methods and possibilities to improve the accuracy of zonal network models. Section III presents results and section IV concludes.

II. METHODOLOGY

A. Description of the case study

The study covers the Central European power system. The following 10 countries are included in the model: Austria, Belgium, Switzerland, Czech Republic, Germany, Denmark, France, Luxembourg, the Netherlands and Poland. The power system data originate from the ENTSO-e Study Model 2020 for Continental Europe [7], which contains data about grid topology and grid equipment (3367 transmission lines, 2339 nodes, 511 generation units). The model only considers the high voltage grid (above 200 kV). The generation technology of each unit is not specified by the ENTSO-E Study Model, but assigned by the authors of this paper based on the operating range of the power plant. In this test system, only conventional generation technologies are assumed to be connected to the high voltage grid. Total installed conventional generation is 205 GW, of which 82 GW nuclear units, 73 GW coal-fired units, 40 GW combined-cycle gas-turbine (CCGT) units and 10 GW peaking units (gas turbines and combustion engines). Demand time series per country come from the ENTSO-e Data Portal [8]. Electricity generation from renewables (wind, solar, hydro and bio) is implemented as load correction, based on historical 2012 generation data and 2010 wind and solar profiles. These demand series are distributed among the nodes based on the load flow solution provided in the Study Model. In this paper, two specific weeks are considered; a high-demand week (Monday February 6 to Sunday February 12, 2012) and a low-demand week (Monday May 28 to Sunday June 3, 2012). Fig. 1 shows the hourly demand for these weeks. The optimal generation scheduling during these weeks is simulated, based on four different network models: a nodal model, a simple zonal model and two improved zonal models.

The simulation results presented in this paper follow from a deterministic unit commitment model formulated as a mixed-integer linear programming problem in the General Algebraic Modeling System (GAMS) and solved with the solver IBM ILOG Cplex 12.5 with an optimality criterion of 1%. The model minimizes total operational system cost, taking into account the technical power-plant constraints and network constraints (DC load flow model). Each week is simulated sequentially in 12-hours blocks with a time resolution of one hour. The model allows loss of load and electricity demand is considered to be inelastic. Hydro pump units, reserve requirements and phase shifters are not considered. Line capacities are reduced by 10 % to account for neglecting reactive currents in the DC load flow [9]. A detailed description of the model can be found in [10].

![Fig. 1. Hourly demand for the two weeks considered in this paper: a high load week in February 2012 (February 6 - 12) and a low load week in May-June 2012 (May 28 - June 3).](image-url)
B. Nodal-zonal network reduction

This paper aims to compare a nodal network model with zonal network models, based on a case study of the Central European power system. As mentioned above, the nodal network model of the Central European power systems, as used in this paper, consists of 2339 nodes and 3367 transmission lines. The nodal PTDF-matrix is known, following from the nodal grid topology and line impedances, as well as the transmission capacity of each line (expressed in MW). The “simple” zonal network model consists of only 10 nodes (each country is represented by one node) and 15 transmission lines (aggregated cross-border lines).

The nodal network description is given by

\[ F_L = PTDF_{nodal} \cdot P_N \]  

with \( F_L \) a 3367x1-vector containing the power flows through the lines, \( P_N \) a 2339x1-vector containing net nodal power injections in the grid (whereby offtake is a negative injection) and \( PTDF_{nodal} \) the nodal PTDF-matrix. The zonal network description is given by

\[ F'_{L'} = PTDF_{zonal} \cdot P_{N'} + F'_{0} \]  

with \( F'_{L'} \) a 15x1-vector containing power flows through the inter-zonal lines, \( P_{N'} \) a 10x1-vector containing zonal power injections in the grid, \( PTDF_{zonal} \) the zonal PTDF-matrix and \( F'_{0} \) the “zero imbalance” flows. “Zero imbalance” flows represent the inter-zonal flows when each zone is balanced, i.e., with zero zonal injection. For nodal and zonal network models, the power flows are limited by the transmission capacity of the lines, respectively as

\[ -L_{cap} \leq F_L \leq L_{cap} \]  

(3)

\[ -L'_{cap} \leq F_{L'} \leq L'_{cap} \]  

(4)

with \( L_{cap} \) and \( L'_{cap} \) the line capacities in respectively the nodal network model and the zonal network model. Equations (1)-(4) hold for every time step.

The reduction from a nodal network model to a zonal network model must be performed for two dimensions: power flows (i.e., going from equation (1) to equation (2)) and transmission capacities (i.e., going from equation (3) to equation (4)).

1) Network reduction: power flows

With regard to power flows, two different approaches are being used to reduce nodal networks to zonal ones. One approach is based on a series of load flow simulations while another approach is based on matrix operations on the nodal PTDF-matrix. In this paper, the matrix operation approach is used. The reduction from a nodal to a zonal PTDF-matrix consists of 3 steps: (1) omitting the rows in the nodal PTDF-matrix corresponding to intra-zonal lines, (2) grouping different nodes into zones based and (3) adding flows in parallel inter-zonal lines into one cross-border line. The resulting zonal PTDF-matrix gives the relationship between a zonal grid injection and the inter-zonal flows in the grid.

The nodal-zonal network reduction is based on two assumptions. First, it is assumed that no congestion occurs within a zone and therefore the intra-zonal lines can be omitted from the network model (see step 1). Second, it is assumed that the spatial distribution of generation and load within a zone is stationary (constant in time) and therefore the generation shift keys are constant in time (see step 2). Both assumptions are only correct by approximation.

The nodal network model contains 3283 intra-zonal lines (out of 3367 lines). During the two simulated weeks (336 hours), 41 of these intra-zonal lines are congested for on average 75 hours. Although only 1.3% of the intra-zonal lines is congested for on average 22% of the time, neglecting these intra-zonal congestions might have a considerable impact on the generation scheduling in the zonal model.

The spatial distribution of generation and load within a zone is given by the generation shift key matrix (GSK-matrix). GSKs indicate the nodal contribution to a change in the zonal balance and can be calculated based on the results from the nodal network simulation. Three different ways exist to determine the nodal contribution to a zonal generation balance change, i.e., according to the merit order, based on the remaining available capacity or based on the production level [11]. The last approach mentioned is used in this paper. Note that in reality, no nodal solution is available ex-ante to calculate the generation shift keys. Therefore the generation shift keys have to be estimated based on historical system data of the grid. GSKs change from time step to time step. Fig. 2 shows the variation in generation shift keys (GSKs are calculated based on the nodal simulation results). For each node in the nodal network, the weekly average generation shift key (in absolute values) and the standard deviation are shown. There is a significant variation in time of the generation shift keys (high standard deviation). The assumption of a spatial distribution of generation and load that is constant in time is hence a rather rough approximation. In this paper, a time-average GSK matrix is used for each of the two considered weeks.

![Fig. 2. The figure shows the weekly average generation shift key of each node for the high load week and the low load week (absolute values) together with its standard deviation. The variation in time of generation shift keys is significant.](image-url)

[4] A generation shift key is calculated as the nodal generation (>0) or load (<0) divided by the zonal balance of the zone to which the node belongs.
In zonal network models, inter-zonal flows might occur even when each zone is balanced (i.e., zero zonal grid injections). Therefore, an additional term has to be introduced in the equation describing these grid flows \( F^{0}_{L} \). The value of this term follows from equation (2), solved with the simulation results of the nodal network simulation. \( F^{0}_{L} \) varies in time (see Fig. 3). The variation (standard deviation) is considerable. In this paper, a time average \( F^{0}_{L} \) flow is used for each of the two considered weeks.

2) **Network reduction: transmission capacity**

In a nodal network model, the transmission capacity of a line is simply determined by the physical transmission limit of the line. In a zonal network model – where inter-zonal lines between the same two zones are aggregated into one inter-zonal link – it is less straightforward to determine the capacity of the aggregated lines. The transmission capacity of an aggregated cross-border line cannot be easily calculated as the sum of all cross-border transmission capacities, but depends on the operation of the whole network and the capacity calculation methodology (e.g., reliability margins) [12]. The cross-border capacity is imposed by the Transmission System Operator (TSO) according to the Available Transmission Capacity (ATC) approach or the Flow-Based (FB) approach. The ATC approach provides a cross-border transmission capacity to the market, regardless of the flows at the other borders of the zone. The FB approach takes account of the impact of flows at other borders and is hence less restrictive than the ATC approach in terms of the transmission capacity that is made available to the market. In this paper, the maximum physical flux at the border is used as the cross-border capacity. This implies that in the model, the inter-zonal lines between two zones are not aggregated into one link but represented as separate lines with each their own physical transmission limit. Depending on the operation of the grid, one of these separate lines can become congested first and this line sets the limit for the cross-border capacity between the two zones. This approach corresponds to a flow-based market coupling.

Note that neither in the nodal network model, nor in the zonal network model, reliability considerations are taken into account (e.g., N-1 security constraint). Therefore, the power flows in the grid might be overestimated by the model. However, this is of minor importance as long as the same boundary conditions apply to all network models discussed in this paper.

**C. Improving the nodal-zonal network reduction**

As mentioned before, the nodal-zonal network reduction is based on the assumptions that no intra-zonal congestion occurs and that the spatial distribution of generation and load is constant in time. However, in reality these assumptions are only correct by approximation. The accuracy of these assumptions depends on the network design (e.g., a meshed grid versus a non-meshed grid), the operation of the power system (e.g., variable load versus constant load) and the granularity of the zonal network model (e.g., the number of zones). The accuracy of the zonal network model can be enhanced by increasing the granularity of the zonal network model or by performing the network reduction separately for different types of grid injections.

Besides the assumptions on intra-zonal congestion and spatial distribution of load and generation, zonal network models can also deviate from nodal network models as the transmission capacities imposed to zonal network models might not completely correspond to the inter-zonal capacities in the nodal network model. This transmission capacity issue is not further elaborated on in this paper, but it is important to mention that a nodal network simulation and a zonal network simulation will only result in the same zonal balances and grid flows if no intra-zonal congestion occurs, the spatial distribution of load and generation is constant in time and equivalent transmission capacities are imposed to both grid models.

1) **Increase granularity of zonal network model**

It is easy to understand that a higher level of granularity of the zonal network (i.e., more zones) increases the accuracy of the network model. The higher the number of zones, the smaller the zones are and hence the smaller the probability of intra-zonal congestion and the more constant the spatial distribution of generation and load within the zones. Increasing the zonal network granularity thus increases the validity of both network reduction assumptions. However, effectively increasing the granularity of the zonal model requires detailed knowledge of the grid at hand. The zonal network model should be composed in accordance with the design and operation of the network. For example, two nodes connected by a transmission line which is often congested, should be allocated to different zones.

Increasing the granularity of the zonal network model does not change the network equations. Equations (2) and (4) still describe the grid constraints. Only the dimensions of the parameters and variables change as the number of zones increases.

![Fig. 3](image-url)
2) Network reduction per type of injection

Up till now, the nodal-zonal reduction considered the whole network at once. The accuracy of the zonal network model can be increased, however, by performing the nodal-zonal network reduction separately for different types of injections. Types of injections can refer to, for example, grid injections from nuclear power plants or grid off-takes from industrial consumers. The spatial distribution within a zone of one type of injections varies less than the spatial distribution of all injections together. In other words, generation shift keys of one type of grid injections are less variable in time than generation shift keys of all injections together. Network reduction per type of injections thus increases the validity of the assumption of stationary spatial distribution of injections, but does not influence the assumption about intra-zonal congestion.

In case of a zonal network model with different nodal-zonal reductions per type of injection, the grid equation become

\[ F_{L'} = \sum_{Y} PTDF_{Y,zonal} \cdot P_{Y,N'} + F_{L}^{0} \]  

(5)

with \( F_{L'} \) a vector containing power flows through the inter-zonal lines, \( P_{Y,N'} \) a vector containing the zonal power injections in the grid of type \( Y \), \( PTDF_{Y,zonal} \) the zonal PTDF-matrix corresponding to injections of type \( Y \) and \( F_{L}^{0} \) the inter-zonal power flows when the zones are balanced. The injections per type are limited to the zonal generation for production-related injections or to the zonal load for load-related off-takes;

\[ 0 \leq P_{Y,N'} \leq \sum_{i \in Y,N'} g_{i} \]  

(6)

\[ 0 \leq -P_{Y,N'} \leq \sum_{j \in Y,N'} l_{j} \]  

(7)

with \( g_{i} \) the power generation of power plant \( i \) and \( l_{j} \) the load of consumer \( j \). Note that load causes grid off-takes (negative injections) and therefore the corresponding injections have to be non-positive. The line flows are limited by the transmission capacity of the lines (see equation (4)). In this paper, the generation shift keys per type of injections are determined based on the production levels in the nodal simulation result. The zero imbalance flow is determined based on the assumption that each generation type contributes to the net zonal grid injection proportionally to its production level.

III. RESULTS

A. Comparing a nodal with a simple zonal network model

First, the performance of the nodal network model (3367 lines and 2339 nodes) is compared with the simple zonal network model (15 lines and 10 nodes). The optimal generation schedule and transmission flows are simulated for the high load week and the low load week. Fig. 4 shows the resulting weekly zonal balances. The deviation between the results according to the nodal network model and the zonal network model is significant, mainly for France. France has a large amount of nuclear power plants with relatively low marginal generation costs. In the nodal network model, the grid constraints limit the usage of French nuclear power. In the zonal network model, less electricity grid constraints are considered and more French nuclear power can be exported to the other countries. The deviation in zonal balances also translates in different inter-zonal flows. It is clear that the simple zonal model of the Continental European power system – with only 10 nodes – oversimplifies reality.

In this study, generation and transmission are optimized simultaneously. As a result, one can compare the optimal power system operation according to a nodal network model with the optimal power system operation according to a zonal network model. In other studies, one optimizes generation and transmission separately, meaning that first generation is optimized based on a zonal network model, after which transmission is validised based on a nodal network with the optimal zonal generation considered to be given. During the transmission validation, redispatching of the optimal zonal generation might be needed to find a feasible solution; so the zonal and nodal generation will slightly differ. However, these studies mainly compare zonal and nodal network models only in terms of deviations in inter-zonal flows, given a certain zonal balance. This study goes further by also considering the deviation in generation between nodal and zonal market models.

The simulations were run on a computer with an Intel Core i7-2620M 2.70 GHz processor and 8 GB RAM. The nodal network simulations ran for about 7 hours, while the zonal network simulations only needed about 2 minutes to find an optimal solution.

B. Improving the accuracy of zonal network models

As explained in section II.C, the accuracy of the zonal network model can be improved by increasing the granularity of the network model (i.e., more zones) or by deriving the zonal network model per injection type. Both options will be discussed in this section.

Fig. 4. Weekly zonal generation balances for the different countries, based on a nodal network simulation and 10-zones zonal network simulation. A positive zonal balance indicates overproduction in the zone and vice versa.
1) Increase granularity of zonal model

The granularity of the zonal network model is increased to 31 zones (versus 10 zones in the simple zonal model) and 60 inter-zonal lines (versus 15 lines in the simple zonal model). The zones are based on the administrative regions given by the ENTSO-e Study Model (see Table I). By increasing the granularity of the zonal network model, both the probability of intra-zonal congestion and the variation in spatial distribution of load and generation (i.e., generation shift keys) will likely decrease.

With the finer-meshed zonal separation of the grid applied to the nodal simulation results, 37 lines are congested for on average 77 hours (compared to 41 lines for on average 75 hours for the model with 10 zones). The total intra-zonal congestion – congested lines times the average congestion hours – slightly decreases with the finer-meshed zonal model, but as the zonal separation is based on administrative regions rather than on network characteristics, the increase in zones helps little to avoid intra-zonal congestion.

Fig. 5 shows the variation in generation shift keys and “zero imbalance” flows for the more detailed zonal model. Recall that the variation in generation shift keys and “zero imbalance” flows is a measure for the correctness of the assumption on constant spatial distribution of load and generation. Both the generation shift keys and the “zero imbalance” flows still vary considerably in time, indicating that there the spatial distribution of load and generation is far from constant in time. This implies that the zonal network model is not very accurate. Increasing the granularity of the zonal network model from 10 to 31 zones causes only a very limited decrease in variability of the generation shift keys and “zero imbalance” (see Fig. 5 versus Fig. 2 and Fig. 3).

One can conclude that the refined 31-zones model brings little improvement compared to the simple 10-zones network model. This demonstrates that it is important to define zones carefully, based on a thorough knowledge of the grid. Zones should be defined in a way that intra-zonal congestion does not occur and that spatial distribution of generation and load is – to a certain extent – constant. In this example, the 31 zones are defined based on administrative regions instead of grid characteristics.

The refined zonal network model does not impact the run time. A simulation for one week still takes about 2 minutes.

2) Network reduction per type of injection

Two different types of injections are considered in the 10 zones of the simple zonal model: injections from generation units (nuclear power plants, coal fired power plants, gas fired power plants and peaking power plants) and load off-takes. By considering different types of injections separately, the spatial distribution of these injections is more constant in time. However, it does not affect the assumption on intra-zonal congestion.

During the nodal-zonal network reduction, the generation shift keys and “zero imbalance flows” are calculated. The variation in time of these parameters is a measure for the correctness of the assumption on constant spatial distribution of load and generation. Fig. 6 shows the weekly average values of the generation shift keys and the “zero imbalance” flows, together with the variation in time (standard deviation). Fig. 6 should be compared with Fig. 2 and Fig. 3, which shows the same parameters for the simple nodal-zonal network reduction. It becomes clear that the variation in generation shift keys and “zero imbalance” flows is lower in the case of a nodal-zonal network reduction per injection type. This indicates that the spatial distribution of the different types of injections is relatively constant in time and that, consequently, this zonal

---

TABLE I. NUMBER OF ZONES (SUB REGIONS) PER COUNTRY.

<table>
<thead>
<tr>
<th>Country</th>
<th># regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>1</td>
</tr>
<tr>
<td>Belgium</td>
<td>8</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>1</td>
</tr>
<tr>
<td>Germany</td>
<td>5</td>
</tr>
<tr>
<td>Denmark</td>
<td>1</td>
</tr>
<tr>
<td>France</td>
<td>8</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>2</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>3</td>
</tr>
<tr>
<td>Poland</td>
<td>1</td>
</tr>
</tbody>
</table>

---

5 A generation shift key of a certain injection type is calculated as the nodal generation or load of that type divided by the total generation or load of that type in the zone to which the node belongs.
The accuracy of zonal network models can be improved by increasing the correctness of these approximations. By increasing the granularity of the zonal network model, i.e., increasing the number of zones, the probability of intra-zonal congestion decreases and the spatial distribution of load and generation is likely more constant in time. However, refining the grid granularity requires a thorough knowledge of the grid design and operation and is therefore rather complex. A new method to improve zonal network models is performing the nodal-zonal network reduction separately for different types of grid injections. This method targets the assumption of constant spatial distribution of generation and load. The spatial distribution of one type of injections, e.g., grid injections from nuclear units, is less time-variant than the spatial distribution of the aggregated injections. This improvement in nodal-zonal reduction is simpler than increasing the number of zones as it requires less knowledge about the grid design and operation.

In conclusion, we have demonstrated that a zonal network model with different power transfer distribution factors per injection type (i.e., different nodal-zonal reductions per injection type) gives a considerable improvement in the grid flow modeling. Moreover, this network improvement is easy to implement as it requires little knowledge about the grid design and operation. Future work consists of testing the new approach on more real-world case studies.

**IV. SUMMARY AND CONCLUSION**

Network models have to be included in generation scheduling models in order to take account of grid constraints. Nodal network models describe the grid constraints in detail, but their practical use in large-scale generation scheduling models is limited due to a high complexity. Therefore, simplified zonal network models are needed. This paper presents a new zonal network model that combines accuracy with convenience.

Three approximations are made when reducing nodal networks to zonal networks: (1) zonal network models neglect congestions within a zone, (2) zonal network models assumes a spatial distribution of load and generation that is constant in time within a zone and (3) the transmission capacities imposed to inter-zonal links in zonal network models do not always correctly represent the actual available transmission capacity between two zones.

**REFERENCES**


