# COST SHARING METHODOLOGIES FOR REMEDIAL ACTIONS IN CROSS-BORDER COOPERATION BETWEEN ELECTRICITY TRANSMISSION SYSTEM OPERATORS

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## Abstract

**The implementation of a methodology for the cost allocation of remedial actions is a necessity for the cooperation of European Transmission System Operators (TSOs). In this study, we adhere to the entirety of the methodology for cross-border congestion management cost sharing developed for the CORE Capacity Calculation Region (CCR) and focus on the variety of power flow decomposition methods that could be used, potentially leading to quantitative differences in the final allocation of congestion management costs. We analyse results from simulating the application of these decomposition methods over a set of test cases based on IEEE benchmarks. Our findings underline the major role of loop flows and reveal that the final cost-sharing outcome is relatively insensitive to the choice of a particular flow decomposition approach. Given that there is no unique answer to the power flow decomposition question, this adds confidence to the cost allocation process envisioned for Europe**

## 1. Introduction

The cross-border integration of national power systems and electricity markets is one of the main pillars of the European energy transition strategy. In order to achieve such integration, the 4th Energy Package of the European Commission (a.k.a. the "Clean Energy Package") upgrades the Regional Security Coordinators (RSCs) into Regional Coordination Centers (RCCs) with an expanded scope of work. This expanded scope also includes the implementation of a methodology for sharing the cost of optimal, coordinated congestion management actions (i.e., redispatching and/or countertrading) between TSOs. The sharing of these costs is a critical coordination tool for the interconnected system. Indeed, transparently reflecting the economic cost of congestion is a requirement for the economically efficient allocation of resources in the short term and for infrastructure planning in the long term. In a zonal market setting, a main challenge in doing so lies in identifying the extent to which specific power injections and demands across the interconnected power grid are burdening/relieving the congestion of any transmission element.

While several empirical methodologies for power flow decomposition have been proposed [1 – 3, 5], by nature there is no exact solution to the problem in question. It follows that there is also no exact solution to the problem of allocating the corresponding congestion management costs. Reference [3] implements the main alternative methodologies that have been proposed for power flow decomposition and compares their performance in terms of resulting flow decomposition over the cross-border branches of a 16-bus, lattice-like network with equal reactance branches, and while ignoring the N-1 security criterion.

In this paper, we seek to analyze the impact of power flow decomposition methodologies on the final sharing of congestion management costs between the different TSOs of an interconnected power grid. With this aim, we simulate the full workflow for cross-border congestion management cost sharing developed for the CORE CCR [4], including not only the power flow decomposition step, but also both the mapping of congestion management costs to congested elements and the final allocation of congestion management costs to the TSOs of an interconnected power system. We implement three alternative methodologies for the critical power flow decomposition step, and specifically the so-called Full Line Decomposition Method [1], the Power Flow Coloring Method from [3] and its variant from [5]. We analyze the relative performance of these methods both in terms of cost sharing and computational burden over a set of test cases on standard IEEE benchmarks (including the IEEE 118 and IEEE 300 bus systems) and while adhering to the N-1 criterion. Our findings underline the critical role of loop flows.

## 2. Methodology

This section describes the workflow developed to simulate the full workflow for cross-border congestion management cost allocation according to ACER [4]. Figure 1 presents the key steps of both the original workflow (left flowchart) and the simulated workflow (right flowchart). In the right part, shapes with a red outline indicate approximate modeling of the original congestion management and cost allocation function. It can be seen that approximations only refer to the input data for the cross-border congestion management cost allocation problem.

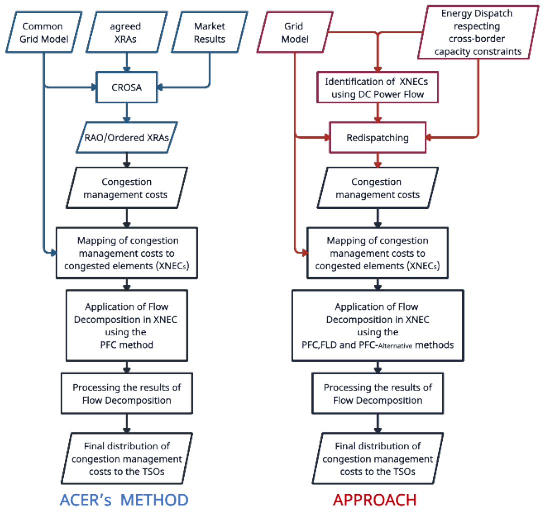


*Figure 1. Original and simulated workflow for congestion management and cost allocation*

### 2.1. Congestion Management Cost Optimization

The resolution of congestion is facilitated by the RCC in collaboration with the relevant TSOs. Specifically, the RCC utilizes the Common Grid Model (CGM) to conduct power flow analysis, identifying congested elements under normal conditions (N) or under contingency conditions (N-1). Subsequently, considering market data and with the consensus of all relevant TSOs, the RCC implements appropriate measures to restore the system security. Such measures may include Redispatching, Countertrading, or non-costly actions such as Phase Shifting Transformers (PSTs) utilization. The optimal combination of these actions resolves congestion. The corresponding cost of these optimal remedial actions is the congestion management cost that must be shared among the relevant TSOs.

In order to simulate congestion management costs on the benchmark systems under study, the first step was to dispatch generation in a way that approximates the market results. For simplicity, and without any loss in generality, this was done by solving a standard Optimal Power Flow (OPF) problem, using the DC power flow approximation and subject to cross-border branch capacity constraints only. Based on this initial dispatch, optimal redispatching actions to resolve any congestion were identified by solving a Security Constrained OPF (SCOPF) problem under the N-1 criterion and subject to both intra-zonal and cross-border branch capacity constraints. The optimal objective value of this SCOPF is our approximation of the congestion management cost to be shared among the relevant TSOs.

### 2.2. Mapping of Congestion Management Costs to Congested Elements

The next step in the methodology involves attributing the total congestion management cost per congested element. For the cost allocation per congestion element, ACER proposes the Least Cost Based Mapping (LCBM) method [4], which is executed independently for each congested element. The aim of this method is to identify the appropriate corrective actions activated with the goal of resolving congestion in the specific element at the minimum possible cost. Subsequently, the total cost of all corrective actions is distributed proportionally to the minimum cost calculated for each congested element. For the first step, a linear optimization problem is solved for each congested element, aiming to find the minimum cost of corrective actions for its corresponding congestion. In our simulated workflow, we have implemented the LCBM method to attribute the total congestion management cost to individual congested elements using again the DC power flow approximation.

### 2.3. Flow Decomposition

Following the mapping of the total congestion management cost to the different congested elements of the grid, the next step is to decompose the flow of any congested element into categorically different components. More specifically, the scope of this step is to decompose the flow of any congested element into:

- An *Internal Flow (IF)* component, corresponding to power exchanges that originate and terminate within the same zone as the congested element.
- A *Loop Flow (LF)* component, corresponding to power exchanges between nodes of a single zone, different than the zone wherein the congested element lies.
- An *Allocated Flow (AF)* component, corresponding to import/export and transit power exchanges.

As already mentioned, in the simulated workflow we have implemented the following three alternative flow decomposition methods from the relevant literature:

*2.3.1. Power Flow Colouring (PFC)* [4]*:* The purpose of this method, described by ACER, is to distinguish the percentage of energy production at each node of the system attributed to local demand and the percentage attributed to commercial energy exchange programs with other zones. This is achieved by dividing the problem into two smaller problems. The first aims to identify the energy flows due to the local demand of each area, while the second focuses on the energy flows due to cross-border commercial energy exchange programs. Using the Generation Shift Keys (GSKs) and Load Shift Keys (LSKs), and knowing the Net Position of the zone, $Zone_{np}$, the production attributed to commercial energy exchange programs per node is calculated:

$$P_{n,Allocated} = \begin{cases} GSKs_n * Zone_{np} \text{ if } Zone_{np} > 0 \\ LSKs_n * Zone_{np} \text{ if } Zone_{np} < 0 \end{cases} \quad (1)$$

With appropriate utilization of Power Transfer Distribution Factors (PTDFs), the allocated flows are calculated. The remaining power at nodes, $P_{n,Balanced}$, is utilized to meet local demand, and with suitable application of PTDFs, the loop and internal flows are computed.

*2.3.2. Full Line Decomposition (FLD)* [1]*:* This method is based on the computation of two matrices. First, the P*ower Exchange (PEX)* matrix represents the power transferred between nodes, where each element $(i, j)$ denotes the power transferred from node $i$ to node $j$. Second, the node to node *Power Transfer Distribution Factor (PTDF$_{node\text{-}to\text{-}node}$)* matrix, unique to each line, describes the change in power flow along the line when power is exchanged between nodes within the transmission system. Through a suitable combination of these matrices, power flow can be decomposed into internal, loop and allocated flow. Allocated flows can be further dissected into import, export and transit flows, a capability that is not present in the PFC method as outlined by ACER [4].

*2.3.3. Power Flow Coloring Alternative (PFCA)* [5]: This method integrates features from both PFC and FLD approaches. The initial problem is divided into two smaller problems, resembling the PFC described by ACER. The first part employs *Generation Shift Keys (GSKs) and Load Shift Keys (LSKs)*, along with the PTDF matrix, to identify internal and loop flows. The second part aims to compute allocated flows using the matrix of *Net Exchanges (NEX),* where each element $(i, j)$ represents the power transferred from node $i$ to node $j$ due to commercial programs. The NEX matrix is similar to the PEX matrix used in the FLD method, with the difference being that it expresses power exchange between network nodes solely due to power exchange programs, rather than the total power exchange as represented by the PEX matrix. The process for computing allocated flows resembles that of the FLD method, effectively combining the PTDF$_{node\text{-}to\text{-}node}$ matrix and the NEX matrix. Allocated flows can be further analyzed into Import-Export and Transit Flows, similar to FLD.

### 2.4. *Allocation of Congestion Management Costs*

Following the decomposition of the flow, flows opposing the final flow, which cumulatively lead to congestion, are eliminated [4]. These flows, termed relieving flows, contribute to reducing congestion. For ease of comprehension, Fig. 2 presents an example for the flow decompositions and the implementation of relieving flows elimination on a hypothetical four-zone interconnected system.

Following the elimination of relieving flows, the separation of loop flows into two distinct categories ensues, each treated differently in the allocation of congestion costs. This separation arises due to a threshold, equal to 10% of the maximum line capacity of the congested line [4]. The presence of loop flows below this threshold in an interconnected electrical transmission system is considered normal. The 10% threshold is equally distributed among the zones of the interconnected system (e.g., for an interconnected system with four zones, the individual threshold is 2.5%). If a zone contributes to the creation of a loop flow greater than its individual threshold, it is deemed a loop flow above threshold. Similarly, if a zone generates a loop flow below its individual threshold, it is termed a loop flow below threshold, and the remaining threshold, if any, is equally distributed among the zones generating loop flow above the threshold. The subsequent association of flow type with congestion creation follows a simple prioritization rule defined by ACER [4]. The congestion management cost allocation for the example of Fig. 2 is illustrated in Fig 3.

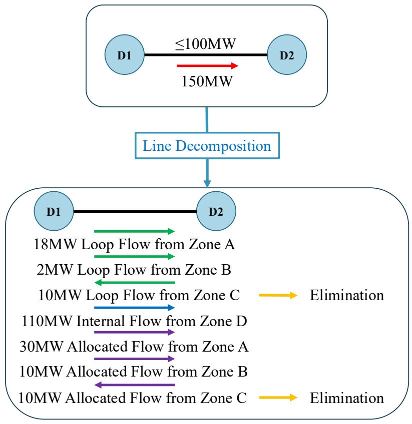


*Figure 2. Flow decomposition and elimination of relieving flows on line 1→2 of zone D within a hypothetical 4-Zone system.*

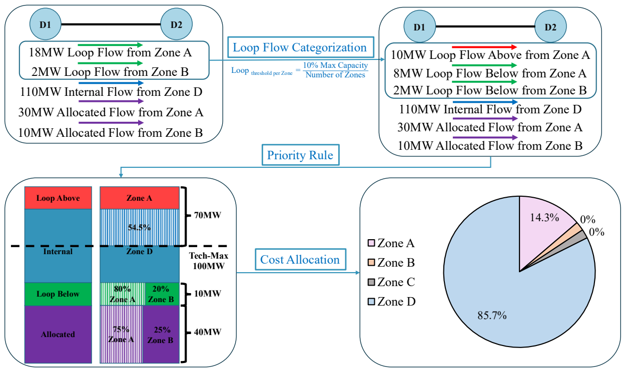


*Figure 3. Congestion management cost allocation example.*

After the decomposition of the flow, the total percentage that each type of flow contributes to congestion is calculated (e.g., 100% of loop flow above threshold and 54.5% of internal flow contribute to congestion in the hypothetical situation of Fig. 3), as well as the percentage by which each zone participates in creating each type of flow (e.g., the total loop flow below threshold is attributed to 80% in Zone A and 20% in Zone B in Fig. 3). For the distribution of congestion management costs per zone, the total percentage contributed by each type of flow to congestion is multiplied by the percentage by which each zone participates in creating each type of flow. The resulting product is then multiplied by the cost of congestion management (e.g., the cost borne by Zone A is 100% * 14.3% * Congestion Management Cost in Fig. 3).

## 3. Case Studies

We have applied the full workflow shown in Figure 1 on several academic benchmarks, and specifically the IEEE 30-bus, 39-bus, 57-bus, 118-bus and 300-bus test cases. All test-case data have been sourced from the benchmark library maintained by the IEEE PES Task Force on Benchmarks for Validation of Emerging Power System Algorithms. For the purposes of our analysis, we have arbitrarily assigned the buses of the aforementioned systems into different zones under the responsibility of different TSOs, thus simulating the operation of multi-zone interconnected systems. The consideration of several alternative case studies and under an arbitrary assignment of buses into zones allows us to extract conclusions that are independent of the topology of the considered test system. All considered test system data are available online[1].

### 3.1. *Mapping of congestion costs to congested elements.*

We start form the IEEE 57-bus system and the computations involved in mapping the congestion management costs to congested elements. As already mentioned, without loss of generality, we compute the congestion management cost to be allocated by (i) initially using a DCOPF to dispatch generation over the whole system subject to cross-border transmission constraints only and (ii) subsequently solving an N-1 secure SCOPF subject to both intra-zonal and cross-border branch transmission constraints. The resulting cost to be allocated amounts to €2790.45.

The mapping of the congestion management cost to the congested elements of the grid is presented in Table 1. The first column of this table identifies the congested element, the second column identifies the network configuration and the third column lists the extent of the overload in relation to the element transmission capacity. The final column lists the congestion cost that is attributed to every congested element and network configuration pair. It can be seen that congestion would only be observed upon occurrence of a contingency in the system, meaning that the N-1 security criterion is the actual reason to deviate from the initial generation dispatch. We further notice the relationship between the overload extent and the mapped amount of congestion management cost. For the same overloaded branch under different contingencies (e.g., the branch linking buses 9, 12) an overload of larger extent implies larger volume of generation that needs to be redispatched, hence greater mapped cost. This implication may not however hold for different branches (even with similar capacities). In the case of different overloaded branches, the generating units that should be redispatched are different and this may in turn affect the congestion cost mapping. For example, the branches linking buses (9,12) and (26,27) are of similar transmission capacity. We observe that for an overload of approximately the same magnitude (roughly 11.5%) under different contingencies the difference in the mapped cost is in the order of 20%.

*Table 1 IEEE 57-bus test case - congestion breakdown*

| ***Congestion (Bus1, Bus2)*** | ***Contingency (Bus1, Bus2)*** | ***Overload (%)*** | ***Cost (€)*** |
|---|---|---|---|
| 4,5 | 8,9 | 2.1 | 11.89 |
| 4,6 | 8,9 | 63.9 | 419.28 |
| 6,8 | 8,9 | 112.3 | 711.84 |
| | 7,8 | 36.7 | 368.94 |
| | 6,7 | 11.3 | 50.30 |
| 7,8 | 8,9 | 23.8 | 242.69 |
| 7,29 | 4,6 | 0.8 | 6.55 |
| 8,9 | 7,8 | 10.1 | 97.16 |
| | 3,4 | 9 | 55.01 |
| | 6,8 | 3.8 | 32.86 |
| | 7,29 | 6.2 | 59.70 |
| 9,12 | 12,13 | 32.5 | 182.25 |
| | 9,10 | 17.5 | 126.66 |
| | 9,11 | 11.5 | 87.65 |
| | 9,13 | 9.3 | 71.38 |
| | 10,12 | 7.9 | 57.19 |
| | 11,13 | 5.8 | 45.34 |
| | 3,4 | 6.1 | 36.51 |
| | 7,8 | 2.2 | 18.74 |
| 26,27 | 8,9 | 11.2 | 108.51 |

### 3.2. *Flow decomposition*

After the mapping of congestion costs to congested elements, the next step is the flow decomposition. In order to expose the properties of the three considered alternative approaches for flow decomposition, we use two selected examples from the IEEE 57-bus test case and a third example from the IEEE 118-bus system.

As a first example, we focus on the most severe congestion on the branch linking buses 6 and 8, under the outage of the branch linking buses 8 and 9. As seen in **Error! Reference source not found.**, this is the network element – contingency event pair with the highest allocated cost. Figure 4 illustrates the alternative outcomes of the flow decomposition using all alternative approaches under study. The results of the different approaches appear similar regarding IF and LF. However, a significant difference arises in AF. The PFC approach yields a different outcome since it cannot recognize the exact power exchanges between network nodes. The FLD and PFCA approaches utilize the PEX and NEX tables, respectively, to do so.

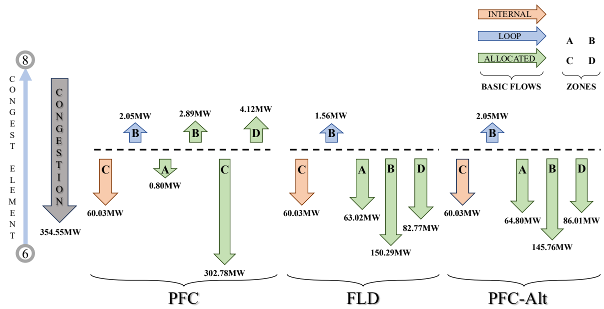


*Figure 4 IEEE 57-bus test case - flow decomposition (example 1)*

For a second example, we chose the congested element for which the alternative methods return the most diverse cost sharing results. It is the branch linking nodes 9 and 12 after the outage of the branch linking nodes 10 and 12. First, we present the result of the flow decomposition step in Figure 5. The common element in the results produced with all alternative flow decomposition approaches is the absence of internal

[1] https://github.com/power-grid-lib/pglib-opf.

flows. The reason for this is systematic. The branch under study is a cross-border branch linking zones D (node 9) and B (node 12). Its ownership is equally shared by the respective TSOs. Figure 6 presents the outcome of the loop flow categorization process. In comparison to both PFC variants, the FLD approach identifies a much smaller LF Above Threshold from Zone B. LF Above Threshold is the flow type with the highest participation in cost allocation. The importance of LF is crucial in cost allocation because, ultimately, it is the only flow type for which the TSO responsible for its creation bears the cost.

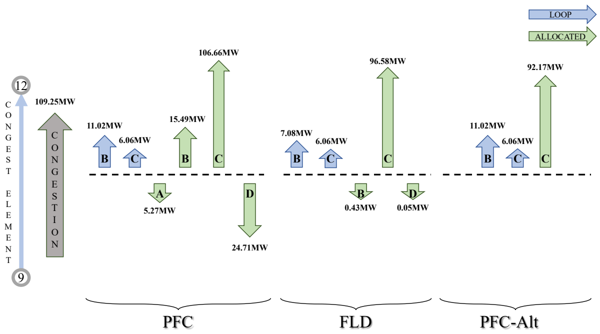


*Figure 5 IEEE 57-bus test case - flow decomposition (example 2)*

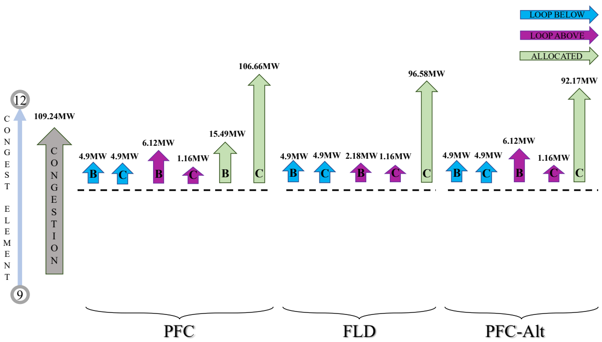


*Figure 6 IEEE 57-bus test-case – loop flow categorization*

As a third and final example, we turn to the IEEE 118-bus test case and the congested element with the largest value of mapped congestion cost. It is the branch linking nodes 47, 69 after the outage of the branch linking nodes 65,68. Figure 7 illustrates the corresponding flow decomposition results with the alternative considered methodologies. It can be seen that there is a difference regarding loop flows. Specifically, both the PFC and PFCA methods identify approximately 40 MW as a loop flow in the relieving direction, which is not the case for the FLD approach. It is important to recall here that these loop flows in the relieving direction will be subsequently eliminated. The remaining loop flows in the burdening direction will subsequently be categorized as "below threshold", ranking third in the order of priority for congestion-causing flows after the "above threshold" loop flows and the internal flows. Ultimately, the final congestion management cost allocation will be the same regardless of the chosen flow decomposition approach. Owing to internal flows only, the zone wherein the congested element belongs (Zone B) is the one that should bear 100% of the congestion management cost. This case therefore exemplifies why it is important to compare the alternatives in terms of the congestion management cost allocation end-result, rather than in terms of the outcome of the (intermediate) flow decomposition step.

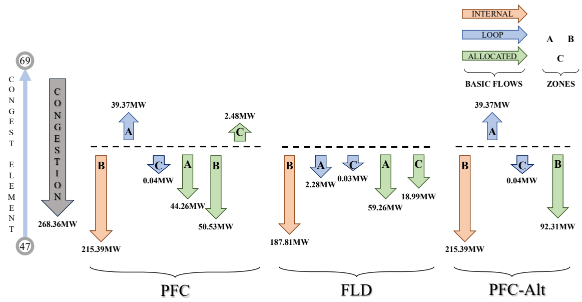


*Figure 7 IEEE 118-bus test case - flow decomposition example*

### *3.3. Congestion management cost allocation overview*

Table 2 presents an overview of the resulting congestion management costs over the different test cases and for all the alternative power flow decomposition methods under consideration. The final row per test case, with the label "NO", represents the situation where no flow decomposition method is applied. Rather, congestion management costs are borne by the TSO that has the ownership of the respective congested element (cross-border interconnectors are assumed to be owned by both concerned TSOs at an equal share).

First, concerning the test case based on the IEEE 30-bus system, it can be seen by the row with the label "NO" that all congested elements are located within Zone A. The reason for this is the fact that, as per the initial dispatch based on the OPF, the power necessary to supply the system demand would be produced by generating units inside this zone. Since Zone A is the sole producing zone, there are no loop flows in this zone, and it is identified to be responsible for congestion under all power flow decomposition alternatives. Hence it would be allocated 100% of the congestion management cost regardless of the chosen decomposition alternative.

The test case based on the IEEE 39-bus system features significantly different results in terms of congestion management cost allocation between the FLD approach and the two variants of the PFC approach. The difference arises from a significantly different calculation of LFs across a substantial number of similar congested elements (over several N-1 states). It has to be noted here that the FLD final cost allocation is very close to the hypothetical allocation in case no power flow decomposition method is used.

The remaining three test cases consistently produce very similar congestion management cost allocation results, irrespectively of the chosen power flow decomposition approach. The results for IEEE 57-bus test case and Zone D are noteworthy. Under the "NO" method hypothesis, 18% of the total cost would be allocated to this zone, suggesting that there is congestion inside this zone or in cross-border branches into (out of) it.  Regardless of the chosen power flow decomposition approach amongst the three considered alternatives, this zone ends up practically not having to pay any congestion management cost. This motivates the use of the power flow decomposition-based approach, as it seems crucial to recognize the zones that are actually responsible for the congestion occurring in/around Zone D.

*Table 2 Congestion management cost allocation overview (%)*

| | | Zone A | Zone B | Zone C | Zone D |
|---|---|---|---|---|---|
| **IEEE 30-bus** | *PFC* | 100 | 0 | 0 | - |
| | *FLD* | 100 | 0 | 0 | - |
| | *PFC-Alt* | 100 | 0 | 0 | - |
| | *NO* | 100 | 0 | 0 | - |
| **IEEE 39-bus** | *PFC* | 33.1 | 65.8 | 1.1 | 0 |
| | *FLD* | 98.6 | 0.3 | 1.1 | 0 |
| | *PFC-Alt* | 33.1 | 65.8 | 1.1 | 0 |
| | *NO* | 98.4 | 0.1 | 1.2 | 0.3 |
| **IEEE 57-bus** | *PFC* | 7.1 | 21.8 | 70.6 | 0.5 |
| | *FLD* | 6.8 | 18.9 | 74.0 | 0.3 |
| | *PFC-Alt* | 6.8 | 21.8 | 71.2 | 0.2 |
| | *NO* | 7.9 | 6.4 | 67.7 | 18.0 |
| **IEEE 118-bus** | *PFC* | 2.0 | 72.3 | 25.7 | - |
| | *FLD* | 1.5 | 73.0 | 25.5 | - |
| | *PFC-Alt* | 2.0 | 72.3 | 25.7 | - |
| | *NO* | 5.3 | 69.2 | 25.5 | - |
| **IEEE 300-bus** | *PFC* | 78.2 | 6.2 | 15.6 | - |
| | *FLD* | 76.2 | 8.1 | 15.7 | - |
| | *PFC-Alt* | 78.2 | 6.2 | 15.6 | - |
| | *NO* | 78.0 | 6.3 | 15.7 | - |

### *3.4. Computational workload*

Table 3 presents the computational workload of applying the considered methods on the IEEE 30-bus and 300-bus benchmarks. All values refer to our implementation of the cost allocation alternatives in Julia, using a computer with an Intel Core i7-1165G7 processor running at 2.8GHz using 16GB of RAM. The implementation of the PFC method has turned out to be advantageous in terms of (lower) computational burden, consistently across all test cases considered. Furthermore, the observed advantage of the PFC method seems to increase with the size of the considered test case. Recalling the considerable similarities in terms of the end result (i.e., congestion management cost allocation) reported in Table 2, this apparent reduced computational workload may well be a decisive factor in the choice of which flow decomposition technique to adopt in practice.

*Table 3 Computational workload overview*

| | Flow decomposition | CPU time (s) |
|---|---|---|
| **IEEE 30-bus** | *PFC* | 0.0048 |
| | *FLD* | 1.1050 |
| | *PFC-Alt* | 1.2346 |
| **IEEE 300-bus** | *PFC* | 10.1839 |
| | *FLD* | 1973.5400 |
| | *PFC-Alt* | 2336.4575 |

## 4. Conclusions

In this paper, we revisited alternative proposals for the allocation of congestion management costs between the TSOs of an interconnected power system. The alternative proposals are differentiated in terms of the methodology employed for the crucial flow decomposition step of the cost allocation process, which serves to decompose congested flow into commercially different flow categories (as in internal flows, transit flows and loop flows). The topic is rather timely in the European context, wherein the integrated operation of the national systems advances further and the expanded scope of work for the so-called Regional Coordination Centres includes the implementation of a methodology for sharing the cost of optimal, coordinated congestion management actions. Our analysis, focusing on the resulting cost allocation, adds to the discussion on top of existing studies comparing flow decomposition alternatives in terms of the resulting flow categorization.

We implemented all alternative approaches in a set of academic benchmarks in order to factor out any potential effect of the particular system topology and allocation of nodes into zones. The main outcome of our study is the observation that the choice of a flow decomposition technique between the three considered alternatives has a very moderate effect on the resulting cost allocation. In larger test-cases (namely the IEEE 118-bus, and the IEEE 300-bus cases) all three alternatives produced practically identical congestion management cost allocation results. Notable differences were reported only in one test-case and particularly the IEEE 39-bus case. Given that there is no unequivocal answer to the power flow decomposition question and electricity injections and discharges are in effect 'pooled' within the transmission grid, we believe that our finding adds confidence to the overall cross-border congestion management cost allocation process. Its end-result seems insensitive to (somewhat arbitrary) assumptions on the origin and destination of specific power exchanges.

We further observed that loop flows have a notable effect on the congestion management cost allocation results. The IEEE 57-bus test case exemplifies such effects best. In the presence of significant loop flows, it is important to rely on a flow-decomposition based cost allocation approach. We finally observed a significant difference in terms of the computational workload implied by these alternative approaches. In our implementation, the standard version of the so-called Power Flow Colouring approach has a clear advantage which increases with the size of the system under consideration. The reason for such difference merits to be investigated in future work, and particularly on real-life applications.

## 5. References


[1] M. Pavesi, J. van Casteren, S. A. de Graaff, The full line decomposition method - a further development for causation-based cost sharing, Cigre Science & Engineering, vol. 9, 2017.

[2] FutureFlow, "Cross-border balancing and redispatching mechanisms tailored to congested borders situation and design of a Common Activation Function", public report, Dec. 2016.

[3] M. Kłos and K. Wawrzyniak, "Comparing Load Flow Decomposition Methods for Cost Sharing of Coordinated European Redispatch," 2019 16th International Conference on the European Energy Market (EEM), Ljubljana, Slovenia, 2019, pp. 1-6, doi: 10.1109/EEM.2019.8916555.

[4] ACER, "Common methodology for redispatching and countertrading cost sharing for the Core CCR in accordance with Article 74 of Commission Regulation (EU) 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion management", Nov. 2020.

[5] D. Vlaisavljevic, I. M. Vlaisavljevic, M. Vukasovic, and Z. Vujasinovic, "Power Flow Colouring: A Novel Power Flow Tracing Methodology Tailored for the European Zonal Electricity Market Design," in *2019 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe)*, IEEE, Sep. 2019, pp. 1–5.