Loop flow estimation – is the cost sharing methodology discriminative?

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***Abstract*—This work analyzes the flow decomposition method used in the methodology for Cost Sharing of Redispatching and Countertrading issued by ACER's decision in 2020. The analysis demonstrates that ACER's amendments to the original Power Flow Coloring method lead to an overestimation of loop flows in importing zones, resulting in unfair cost allocation. The original PFC method is compared against ACER's version, illustrating how ACER's approach inflates internal and loop flow calculations. It is argued that ACER's proposed remedy is insufficient. We conclude that ACER's current methodology can lead to financial discrimination against importing zones and call for corrective measures to ensure a fairer cost-sharing framework.**

***Index Terms*—regional operational security coordination, redispatching, loop flows, polluter-pays**

I. Introduction

A. Legislative context

In November 2020, ACER adopted a methodology for the Cost Sharing of Redispatching and Countertrading [1] [2], which complements the Regional Operational Security Coordination (ROSC) framework. This methodology is designed to provide a transparent and coordinated approach to managing grid congestion across borders, a key aspect of ensuring a secure and efficient European electricity system. By implementing common measures for grid balancing, the methodology requires a fair and transparent cost-sharing mechanism, which is where RDCTCS plays a pivotal role.

The RDCTCS methodology follows a series of steps, including the identification of relevant cross-border network elements, the mapping and attribution of costs, the decomposition of flows, and the final distribution of costs among the involved parties. However, the flow decomposition method, as outlined in the methodology, has been identified as potentially unfair, particularly for importing zones. The adopted solution tends to overestimate the loop flow levels in these zones, leading to disproportionate cost allocations.

Overestimated loop flows result in higher costs for the zones where the flows are produced, as different categories of flow are either borne by the network element owner or the so-called "polluter" under the polluter-pays principle. In this context, zones responsible for causing excess flows are expected to financially contribute to alleviating these flows through redispatching and counter-trading measures within the ROSC process. However, the overestimation in the flow decomposition leads to an unfair allocation of these costs.

This paper further explores examples where this overestimation occurs and discusses corrective measures to address the issue. The proposed corrections aim to ensure a more equitable cost-sharing framework, in line with the principles of fairness and transparency, improving the overall efficiency of the RDCTCS methodology in managing cross-border grid congestion.

B. Overview of the cost sharing process

RDCTCS methodology encompasses several steps to be untertaken in pusuit of the ultimate assocition costs with the TSOs. It consists of at least four distinctive stages [16] (Fig. 1):

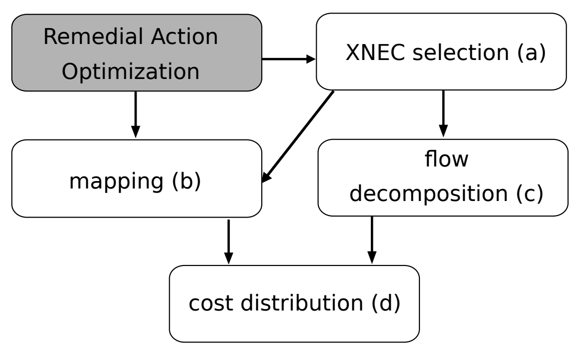

Fig. 1. Stages of cost sharing process according to RDCTCS.

Remedial Action Optimisation, introduced by ROSC is aimed at selecting both a set of measures that provide a secure operating point, and assessing the overall cost of subsequent actions (this step is formally outside RDCTCS, but it introduces crucial input to the described process):

(a) XNEC selection—to determine the set of cross-border relevant network elements under contingency (XNEC) that are subject further cost sharing operations,
(b) mapping—to estimate the aforementioned costs per network element,
(c) flow decomposition—to identify the influence of each zone on every network element under consideration and divided into flow types,

(d) cost distribution—prioritize (decomposed) flow components and associate them with costs obtained from mapping, thus leading to attribution of cost to particular XNECs,

This work is concentrated on implementation of flow decomposition and, consequently, the remaining elements of cost sharing design will not be discussed in detail.

Next section (II) explores the subject of flow decomposition for the purpose of cost sharing calculations. Section III is aimed at confirming theoretical intuitions by an intuitve example of consequences. Finally (IV) we formulate some conclusions and recommendations for TSOs and the Agency.

II. Theory of flow decomposition

A. Flow categories

Historically, the European Network of Transmission System Operators for Electricity (ENTSO-E) used to classify power flow components on network elements into four categories: internal, import-export, transit, and loop flows [15], later amended by CORE TSO's who postulated a fifth category - PST flow. ACER, adopted ENTSO-E's categories, merging two of them into a single cross-zonal trade related *allocated flow*. RDCTCS methodology adopted in 2020 utilizes such flow types as:

(a) *Internal flows* occur when the source, sink, and entire XNECs are within the same zone.
(b) *Loop flows* occur when the source and sink are in the same zone, but the XNEC (or part of it) is in a different zone.
(c) *Allocated flows* occur when the source and sink are in different zones, regardless location of XNECs.
(d) *PST flows* originate from volatge angle shift introduced by phase-shifting transformers (PSTs).

B. Flow decomposition methods

A reliable identification and assessment of the flow components on critical network elements demands a robust methodology substantiated by a solid numerical evidence. In order to decompose power flow it is necessary to identify and process load flow data reflecting power exchanges within and between zones. Such a question is being addressed by the algorithms called here by a common name of the load flow decomposition methods [15].

Among dedicated methods one can distinguish significantly different paradigms to approach the problem of decomposition; the authors either start with the analysis o full, network-based identification of source-sink pairs in nodal resolution [7] [6] [10] [5], or utilize the zonal concept from the very beginning (distinguishing between flows induced by inter-zonal exchange and intra-zonal transactions) and follow with nodal modeling of power flows [12] [3]. In the following sections only the last one will be discussed, as it serverd for the purpose of extablisthing RDCTCS methodology.

C. The original PFC method

The Power Flow Component (PFC) method [1] employs a top-down analysis, leveraging the energy market's zonal structure before proceeding to nodal-level power flow analysis. The core concept involves decomposing the analyzed system's operational state into two models: a balanced model and a model with exchanges. PFC uses the model with exchanges to identify interzonal commercial flows, while the balanced model quantifies loop and internal flows. This procedure can be summarized in three steps:

(i) Sub-model Creation: The initial load flow model is partitioned into two sub-models. This division separates nodal power injections and withdrawals into two groups: (i) intra-zonal power exchange and (ii) inter-zonal commercial power exchange. The balanced model is generated by reducing the net position of exporting zones (shifting down excess export) or increasing the net positions of importing zones (decreasing excess import). Methods for establishing the balanced model's operational points include merit order, Generation Shift Keys provided by Transmission System Operators (TSOs), or proportional scaling of nodal injections/withdrawals. Regardless of the choice of an ultimate approach, according to the authors of the method "when balancing exporting area, total generation in area *O* needs to be shifted down to the total load in area *O*" and "when balancing importing area, total load in area *O* needs to be shifted down to the total generation in area *O*" [4]. This detail is of special importance and will be referred to in the next section.
(ii) Nodal Grouping for Power Exchange: These sub-models are then used to identify flow components. Power flow analysis is conducted on each zone of the balanced model independently, assuming no generation or demand in other zones. For the model with exchanges, the Equivalent Bilateral Exchange (EBE) method [5] is used to determine inter-zonal power exchange. EBE posits that each source supplies energy to every sink (regardless of nodal distances), with the power exchanged proportional to the generation at the source and the sink's load fraction relative to the total nodal loading.
(iii) Flow Categorization: Flow components derived from the balanced model identify internal and loop flows. Components from the model with exchanges represent interzonal commercial flows (import/export and transit flows).

D. Amendments to PFC introduced by ACER

ACER, while issuing their decision, amended flow decomposition method in a single important manner. The method of establishing a self-balanced model for loop flow calculation is described in a following way:

"The nodal injections used for the calculation of loop flows and internal flows are the nodal injections calculated pursuant to paragraph 3 reduced by nodal injections for allocated flows pursuant to paragraph 6." [2]

Paragraph 3 describes creation of operation points for further analysis as the transition from the AC power flow (which

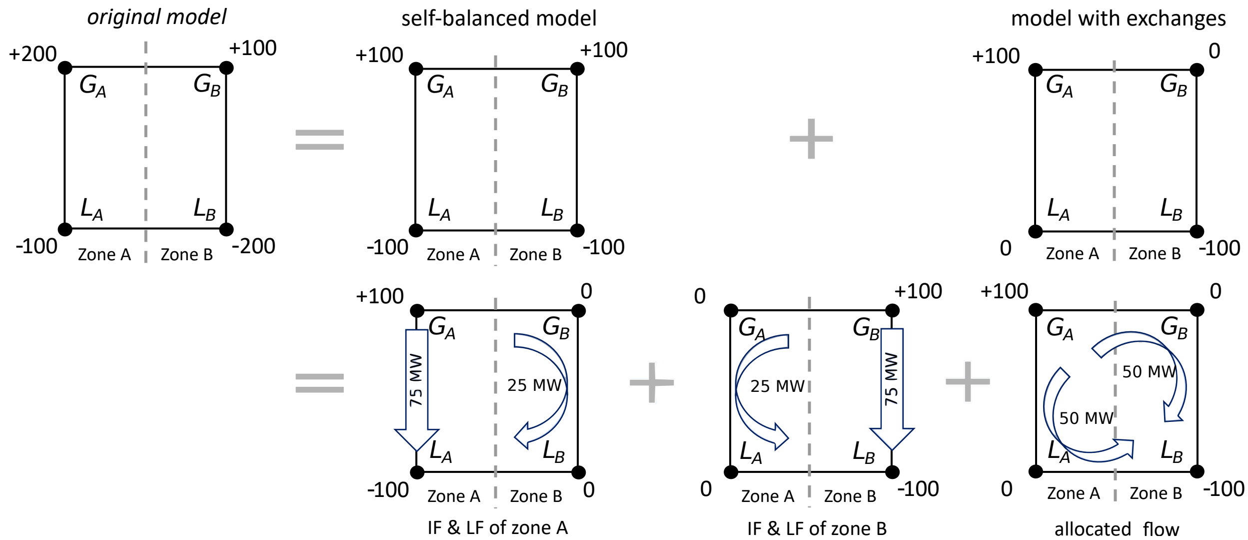

Fig. 2. Flow decoposition scheme according to original PFC method. IF and LF stand for internal flows and loop flows, respectively

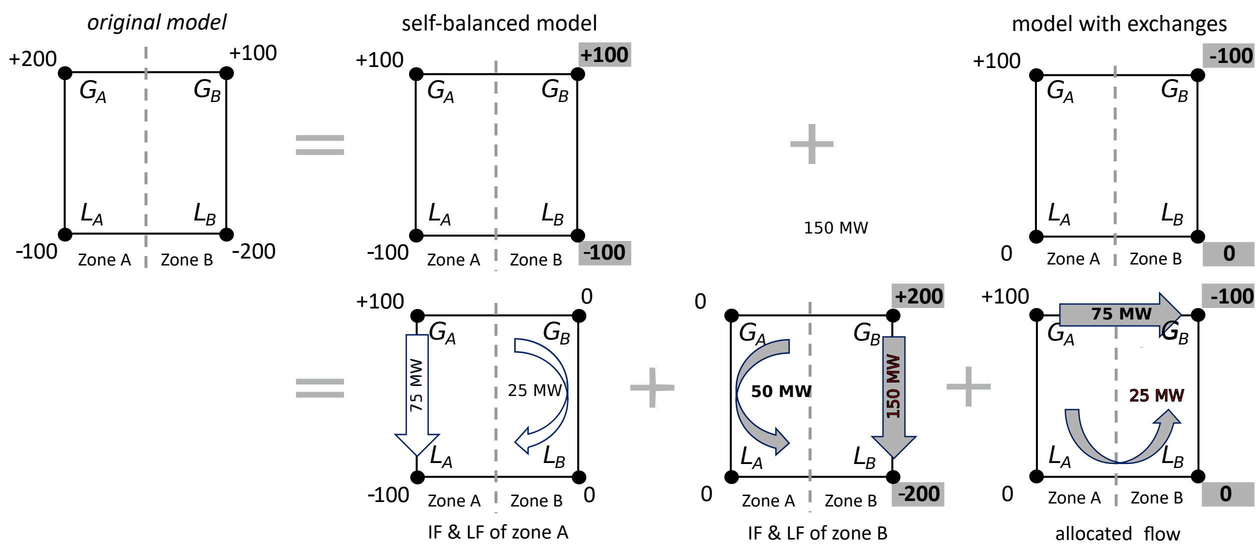

Fig. 3. Flow decomposition scheme according to ACER's version of PFC. IF and LF stand for internal flows and loop flows, respectively. Nubers on gray background indicate differences in respect to original version of PFC.

includes losses of power due to network transmission) into idealized, lossless DC power flow-related model. Paragraph 6 establishes that the :

"The nodal injections for allocated flows are calculated by multiplying the net positions contained within the CGM, with the factors contained within the GSK that is used in the application of dayahead capacity calculation methodology and/or intraday capacity calculation methodology by the concerned Core and non-Core bidding zones (...)". [2]. In other words, having in mind that for almost all operational cases, shift keys used in capacity calculation process refer solely to generation, only the generation side would be subject of shift, while producing self-balanced model. Especially, using to PFC's authors language: when balancing importing area, total GENERATION in area O needs to be shifted UP to the total generation in area O (capital leters indicate differences form the original proposal, described in section II.C).

III. Analysis of Consequences

Our contention is that ACER's regulation introduces a mechanism that overestimates the volume of internal and loop flows in zones with a negative net position (i.e., importing power in a particular Market Time Unit). The mechanism of this overestimation is illustrated by the following examples.

Figure 2 depicts loop flow estimation according to the original version of the PFC method. The operating point under analysis (the original model) is first decomposed into a self-balanced model and a model with exchanges. Creating the self-balanced model follows the convention of the PFC authors (i.e., for an importing zone, the load value is scaled down). Next, the self-balanced model is further decomposed into another pair of models, each associated with a single zone's generation only. The importing zone (B) now exhibits 75 units of internal flow and also produces 25 units of loop flow. This result is intuitively consistent with the original input data—if 100 units of generation and 200 units of load are observed, internal exchange values greater than 100 would contradict the notion that an area cannot internally exchange more than it either internally generates or internally consumes.

The decomposition under ACER's assumption is depicted in Fig. 3. This time, a self-balanced model is built for the importing zone by scaling up generation so that it meets the absolute value of the load. As a result, the internal exchange is estimated as 200 units, leading to 150 units of internal flow and 50 units of loop flow. These numbers are doubled compared to the original version of the method. This also contradicts the intuitive expectation regarding the decomposition's result—more energy is claimed to be internally exchanged than the volume of domestic consumption.

Why is the overestimation of some flow categories considered a problem? The answer lies in the cost distribution process, which (to calculate the ultimate TSO's financial contribution) prioritizes flow components to be penalized if measures for alleviating congestion need to be taken. The methodology states that the cost of reducing congestion in the presence of loop flows is to be attributed first to the zone responsible for this flow component (such a rule is often referred to as "polluter pays" or "causer pays"). Figures 2 and 3 allow us to observe how 75 units of burdening power flow between nodes L_A and L_B are decomposed (this is summarized in Fig. 4).

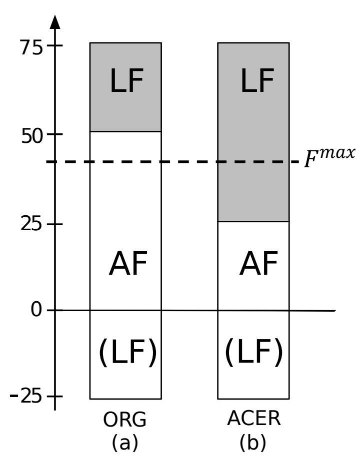

Fig. 4. Decoposition of burdening flow components (positive values) and relieving flows (negative values) according to both versions of PFC: (a) the original one and (b) introduced by ACER

Let's assume the flow limit (F^{max}), which accounts for existence of relieving flow (25 units) is somewhere below 50 units (dashed horizontal line). This means that, in case (a), financial responsibility for bringing the power flow back to the limit (by introducing remedial actions) is split between the causer of LF and the owner of the network element. However, in case (b), this is solely a matter of the causer's payment. This reasoning provides evidence that once overestimation of loop flow occurs, it can lead to financial discrimination of any zone that remains a net importer.

Surprisingly, ACER seems to agree with such view. In their decision we read: *"Some Core TSOs and NRAs expressed concerns that the generation shift key used in capacity calculation is not appropriate for the flow decomposition for importing bidding zones (i.e. bidding zones that import electricity in a specific hour). This is because the generation shift key used in capacity calculation models the import of electricity as reduction of generation in such zone, whereas in flow decomposition the import of electricity is proposed to be modelled as increase of consumption in such bidding zone. Therefore, flow decomposition with the generation shift key from capacity calculation would artificially increase the internal exchanges in such bidding zones (which are calculated in the absence of electricity imports) and thereby increase loop flows and internal flows. ACER agrees with these concerns and suggested that the concerned TSOs try to harmonise generation shift key methodology between capacity calculation and flow decomposition such that the same assumptions about imports of electricity are made in both areas. This is needed to ensure that the flow components calculated during capacity calculation are aligned as much as possible with the flow components calculated during cost sharing. With this regard, the generation shift key method defined in capacity calculation methodologies should be flexible enough to accommodate this consistent approach."* (paragraph 102 of [1])

IV. Recommendations and Conclusions

In light of the harmful phenomenon of discriminatory treatment with respect to some zones (more specifically, some TSOs and all consumers within their control area who contribute to the tariff), ACER's proposal of remedies cited above seems unsatisfactory. The measure of harmonizing Generation Shift Keys (GSKs) so that they serve both capacity calculation and cost-sharing methodologies appears to be of little value. The goals of capacity calculation and cost-sharing processes are different. Whatever form the harmonization takes, it will not change the general market coupling design rule, which is that flexible generation competes between zones to satisfy the demand of little or no flexible generation. This assumption supports the contemporary interpretation of GSKs in the capacity calculation process. The question of whether shift key parameters that serve both purposes can be found remains officially unanswered. In light of this, ACER seems to be referring to a future, potentially non-existent solution to an already confirmed real problem. What alternatives can be then suggested? First, using the original version of flow decomposition method. It is going to be sufficient remedy for loop flow overestimation problem. What alternatives can then be suggested? First, using the original version of the flow decomposition method. This would be a sufficient remedy for the loop flow overestimation problem. Furthermore, the issue of different scaling coefficients between processes of capacity calculation (later also: allocation) and cost sharing can be treated in different manner, e.g. by introducing another flow category which reflect modeling inconsistencies. Such flow component could be used as a "translation" between requirements of capacity allocation language (allocated flow according to Market Coupling) into cost sharing language where allocated flow, as perceived in the allocation process, is no longer valid or useful. The proposal of such decoupling of language used for power flow description will be the subject of future work in this subject. Furthermore, the issue of different scaling coefficients between the processes of capacity calculation (and later, allocation) and cost sharing can be addressed in different ways, for example, by introducing another flow category that reflects modeling inconsistencies. Such a flow component could be used as a "translation" between the requirements of the capacity allocation language (allocated flow according to Market Coupling) and the cost-sharing language, where the allocated flow, as perceived in the allocation process, is no longer valid or useful. The proposal for such a decoupling of the language used for power flow description will be the subject of future work on this topic.

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