Computers and Electrical Engineering 000 (2017) 1–17

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

# An efficient cost based allocation approach for individual generators associated with the system☆

Debashish Bhowmik*, A.K. Sinha

*Department of Electrical Engineering, National Institute of Technology Silchar, Assam, India*

ARTICLE INFO

*Article history:*
Received 18 April 2017
Revised 21 December 2017
Accepted 21 December 2017
Available online xxx

*Keywords:*
Power flow tracking
Power tracking coefficients
Power sharing methodology
Transmission loss allocation
Individual cost allocation

ABSTRACT

This paper presents a maiden alternative approach to the cost based allocation over the transmission network for individual generators associated with the system. A modified method is proposed by which the proportion of power going from an individual generator to the loads, and to the rest of the transmission network can be traced in a grid system. Also, the revenue collected from the customer side for all associated producers separately can be determined. The developed technique has been experimented successfully on a 39-bus New England Power System and to validate the method, the outcomes of the projected algorithm of the test system are compared with the power flow solution obtained by using the sequential quadratic programming method. The comparative analysis reveals that the results obtained from both the methods are nearly the same under different loading conditions, proving the accuracy and robustness of the proposed method.



## 1. Introduction

The electrical power tracing over systems has been gradually needed due to the variations in electrical energy over the power system and the disparity between the power generated and the power demand due to uncertain system shutdowns. The effective operation of electrical power systems necessitates the balance to be maintained between the total power generated and the total load demand along with the associated system losses. Even a minor alteration in demand from its nominal value, results deviations in the individual generation as well as overall transmission losses, which may yield unwanted effects in the system. For dealing with this type of situations, the amount of power flowing from an individual generator to a particular load has to be estimated. This can be achieved with the help of power flow tracking (or tracing) whose major objectives are to trace the overall power flow as well as the transmission line losses over the system.

The power tracing method has been introduced by Bialek [1] using upstream and downstream algorithm for finding the inflows and outflows from and to a particular bus. The MW-MILE method was taken into consideration in [2] to trace the output of each and every generator as well as the input to each and every load. The method assumes that the power inflows and outflows are shared proportionally. The method requires inverting a sparse matrix of rank equal to the number of network nodes. The method has been used to deal with the transmission supplementary charge to real and reactive power loads. The authors in [3] presented a technique to determine which load is fed by which generator, usage of transmission line by generators and generator's contribution to the system losses. By assuming proportionality, contributions of generators to the load and system losses have been calculated. To avoid the problem arising from the nonlinear coupling between real and

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. J. Yogapriya.

* Corresponding author.
*E-mail address:* debashish.electrical@gmail.com (D. Bhowmik).

https://doi.org/10.1016/j.compeleceng.2017.12.040

reactive power flows caused by losses, the authors in [4] translated all power injections into real and imaginary currents. The method then tracks these currents to calculate the amount of current each generator supplies to each demand. The authors in [5] have applied graph theory for evaluating the influences of individual generators and demands to transmission flows and active power transfer between them. The authors in [6] determined the influence areas and compute the network losses, based on circuit theory analysis, which are shown by the connection between their lines independent of the slack bus position. In [7], the authors displayed the reasons behind the circulating power and also proved the presence of circulating power by applying graph theory. After that optimal power flow approach is recommended to abolish the circulating power. In [8], the authors modified the proportional sharing principle using game theory and information theory. The method showed that the Shapley value solution concept, which fulfills all properties one may demand of a loss allocation scheme, validates the proportional sharing rule and also the rule can be derived from the maximum entropy principle. Based on power flow tracing techniques, a new proposal for the charging of transmission losses under the new trading arrangement is introduced in [9], which finds the power contribution of consumers in line power flows throughout the network. The analysis showed a constant pattern of power flow shares in lines to consumers, which can be utilized in ex-ante transmission pricing for a network. A combination of graph based and linear equations based tracing approach of transmission valuing for cross-border trades have been suggested and validated in [10]. The approach allows each country to use a diverse internal transmission pricing methodology, i.e., it keeps the principle of subsidiarity. The data essential are the flows in the tie-lines and the charges to be applied to the border nodes in each country. The approach is illustrated on the IEEE-118 node network partitioned into four areas, each with a different internal transmission pricing method. The suggested methodology is shown to be simple, transparent and very fast and it can deal effectively with cyclic flows. The authors in [11] proposed a method for real and reactive power tracing which gives an appliance for tracing production costs and assigning charges for use of transmission line. A new pattern was proposed by the authors in [12] that tries to capture the best among the post-facto analysis and postage stamp method by exploring variation of the solution space of the tracing problem, within the given constraints. Proportional sharing is not an essential characteristic of the system, it is a rule enforced to attain individuality of the solution in a reasonable manner. In [13], the authors have proposed an alternate parameterization scheme for the continuation load flow technique using actual power losses in transmission lines as parameters. An analytical model and algorithm for tracing power flow (TPF) has been presented by the authors in [14]. In order to build the analytical model of power transfers between generators and loads, the extended incidence matrix, generation and load power vectors, and distribution factor matrix are derived, by applying the obtained results of an AC or DC power flow solution. The advantage of the proposed method lies in the fact that the matrix theory is used directly to build the TPF model, and proportional sharing assumption in the power flow distribution is not required. An active power tracing strategy for estimating the ex-ante point of connection rates for the members of decentralized market has been provided by the authors in [15]. In [16], the aim of the author is to determine the amount of power flow sent by a sending node to the load node, such that the flow decomposition arising from this task is in such a way that each branch flow is broken into parcels (as much as possible) of the same orientation in order to provide a sensible tool for transmission cost allocation. Based on the physical flow in the network, the authors in [17] presented a simple power flow tracing and loss allocation method. The proposed method can be applied easily and directly, and it works on the principle of proportional sharing. It can be used for tracing both active and reactive power. The authors in [18] presented a fast technique for splitting boundary of power system controlled islanding, the main aim of which is to minimize the load-generation inequity in each island. The method contains three phases, namely, defining the domain of each generator according to power flow tracing algorithm, determining an initial splitting boundary based on the grouping information of generators, and refining the initial one to get the final splitting boundary. The authors in [19] resolved the power flow over transmission lines into generation driven components. The characteristics of additivity, symmetry and conservation are merged in electrical circuit analysis equations, for estimating the power flow over transmission line under the deductive reasoning of Shapley theorem. In [20] the authors proposed a modified method of tracing problem based on Bialek's method where there is no need to calculate matrices for upstream and downstream distribution, nodal demand and nodal generation, which leads to faster computation.

In view of the above discussion, this paper aims to propose a power sharing methodology and power tracking coefficient for estimating the contribution of all the individual generators to the associated demands. Moreover, it presents an alternative approach to finding the revenue collected for the energy consumed by the individual customers, and the profit gained by individual producers associated with the power production of the system. Also, it presents an analysis using the proposed methodology on the system under consideration with the variations in load demand, to justify the accuracy and robustness of the same. The main objective is to allocate the power throughout the system for individual producers under economic consideration.

The rest of the paper is organized as follows. Section 2 describes the proposed power sharing methodology. In Section 3, the mathematical formulation for power flow tracking has been explained. Section 4 presents the detailed description of locational marginal pricing. Section 5 discusses the steps of the proposed algorithm. The application of the proposed approach on a 39-bus New England test system with various system loading conditions is discussed in Section 6. Finally, Section 7 summarizes the main conclusions of the work.

Please cite this article as: D. Bhowmik, A.K. Sinha, An efficient cost based allocation approach for individual generators associated with the system, Computers and Electrical Engineering (2017), https://doi.org/10.1016/j.compeleceng.2017.12.040