

Development of a generation dispatch algorithm for small and medium hydropower plants supplying EV charging stations considering transmission line losses

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ABSTRACT

This paper proposes a novel power dispatch method for small and medium hydropower plants supplying energy to electric vehicle (EV) charging stations, explicitly considering transmission power losses. Unlike conventional approaches where losses are treated iteratively or approximated, the proposed method integrates loss components directly into the dispatch formulation via source-dependent loss coefficients. This enables an accurate representation of the impact of transmission distance and line characteristics on each generation unit. Although several studies have considered transmission losses in economic dispatch problems, limited attention has been given to deriving explicit analytical solutions for distributed hydropower systems supplying EV charging stations. This research gap motivates the development of the proposed loss-aware power allocation method. A key contribution of this work is the development of an explicit solution that determines generator outputs without relying on complex iterative algorithms, thereby significantly improving computational efficiency. The method is validated using Matlab/Simulink simulations with a 24-hour time-varying load profile. Results show high accuracy and stable performance, with generation units having lower loss coefficients being preferentially dispatched. The findings demonstrate that the proposed approach not only reduces computation time but also enhances the physical realism of the dispatch model, making it suitable for practical applications in distributed hydropower systems integrated with EV charging infrastructure.

Keywords: Economic dispatch; Hydropower; Transmission losses; EV charging stations; Distributed generation.

1. INTRODUCTION

In the context of the global energy transition toward carbon emission reduction, the electrification of transportation is accelerating rapidly, particularly with the widespread adoption of electric vehicles (EVs). The increasing number of EVs has led to a growing demand for large-scale charging infrastructure, introducing a new type of load characterized by temporal variability and strong dependence on user behavior [3]. Recent studies indicate that EV charging loads can significantly affect daily load profiles and may impact power system operation if not properly coordinated [5, 6].

At the same time, the utilization of distributed energy resources has gained increasing attention. Among these, small and medium hydropower plants play an important role due to their fast response capability, low operating cost, and high operational flexibility [1, 2]. These characteristics make them well-suited for supplying energy to EV charging stations in distributed areas. However, due to the geographical separation between generation sources and loads, transmission power losses become a critical factor that directly affects the efficiency of energy delivery [3, 4]. Although transmission losses have been considered in many economic dispatch studies, most existing approaches rely on iterative optimization techniques or simplified loss approximations. Furthermore, limited attention

has been given to deriving explicit analytical solutions for distributed hydropower systems supplying EV charging stations. Therefore, developing a loss-aware dispatch method with an explicit solution remains an important and meaningful research direction.

In practice, neglecting transmission losses in power dispatch may lead to inaccurate representation of actual operating conditions, resulting in deviations in evaluating system performance. Therefore, it is essential to develop dispatch methods that explicitly consider transmission losses in order to better capture the physical characteristics of power systems [3, 4]. In addition, recent studies on EV loads and distribution systems highlight the importance of considering load location and network conditions to improve the reliability of analytical results [5, 6].

Economic dispatch (ED) considering transmission losses has been extensively investigated in modern power systems. Classical approaches are typically formulated using Lagrange multipliers and B-coefficient loss models, where generation costs and network losses are optimized simultaneously. More recently, distributed optimization, quadratic programming, and fixed-time consensus-based methods have been proposed for power systems with renewable energy sources and electric vehicle charging loads [7, 8]. Although these methods provide satisfactory optimality, most of them require iterative computations and repeated updates of Lagrange multipliers, which may increase computational burden in real-time applications.

Several studies have incorporated EV charging demand into dispatch problems. Shafie-khah et al. [5] investigated optimal demand response programs for electric vehicle parking lots in distribution systems. Liu et al. [6] investigated economic dispatch in distribution networks with EV charging integration. However, these approaches primarily focus on generation cost optimization and often treat transmission losses as secondary constraints.

An analytical approach to economic dispatch was presented by Lam et al. [9], who employed variable substitution to derive a direct matrix solution relating generator outputs to total load demand. For fixed generation cost coefficients, the coefficient matrix is constructed and inverted only once, allowing generation outputs to be updated without iterative optimization or explicit computation of Lagrange multipliers. However, transmission losses were neglected in that formulation. This provides a methodological basis for investigating analytical power allocation methods that explicitly account for transmission losses in distributed hydropower systems supplying EV charging stations.

Therefore, there remains a need for analytical dispatch methods capable of explicitly incorporating transmission losses while maintaining low computational complexity. This motivates the development of the proposed dispatch algorithm.

The main contributions of this paper are summarized as follows: A transmission-loss-aware dispatch formulation for distributed hydropower systems supplying EV charging stations is developed. An explicit analytical solution is derived in matrix form without requiring iterative optimization procedures. The computational characteristics and applicability of the proposed approach are analyzed and discussed. Simulation studies are conducted under time-varying EV charging demand profiles.

Motivated by these challenges, this paper proposes a power dispatch method for small and medium hydropower plants supplying energy to EV charging stations, taking into account transmission losses from generation sources to load points. The method is developed by modeling source-specific loss coefficients and integrating them directly into the dispatch process, enabling efficient and realistic determination of generation outputs.

Simulation results in the Matlab/Simulink environment with a 24-hour time-varying load scenario demonstrate that the proposed method achieves reasonable power allocation, where generation units with lower loss coefficients are preferentially dispatched. This confirms the

validity and potential applicability of the method in modern power systems integrated with EV charging infrastructure.

2. POWER DISPATCH ALGORITHM FOR SMALL AND MEDIUM HYDROPOWER PLANTS SUPPLYING EV CHARGING STATIONS

Consider a system consisting of N generation sources (or supply stations), where the i -th source provides an output power P_i ($i = 1, 2, \dots, N$) to meet the EV charging demand. Corresponding to each source, the transmission line resistances are denoted as $r_1, r_2, \dots, r_N$. According to [2], the transmission power loss on the lines is determined as follows:

$$\Delta P_i = \frac{P_i^2 + Q_i^2}{U^2} r_i \quad (1)$$

Here, Q_i represents the reactive power. In EV charging stations, the reactive power component is typically negligible due to the use of power electronic converters equipped with power factor correction (PFC), which ensures operation at a near-unity power factor (i.e., $\cos \varphi \approx 1$). Under such conditions, the reactive power demand is very small compared to the active power and has a limited impact on power dispatch. Therefore, Q_i can be reasonably neglected in the formulation to simplify the analysis without significantly affecting the accuracy of the results.

Accordingly, the output power P_i is determined as follows:

$$\Delta P_i = \frac{P_i^2 r_i}{U^2} \quad (2)$$

Let us define:

$$C_i = \frac{r_i}{U^2} \quad (3)$$

Thus, the power loss due to the transmission lines is given by:

$$\Delta P_i = C_i P_i^2 \quad (4)$$

The total transmission power loss associated with supplying the EV charging stations can be expressed as:

$$\Delta P = \sum_{i=1}^N \Delta P_i = \sum_{i=1}^N C_i P_i^2 \quad (5)$$

The objective is to determine the optimal allocation of ΔP that minimizes the total power loss, subject to the power balance constraint that the total generation equals the total demand of the EV charging stations, i.e.,

$$P_1 + P_2 + \dots + P_N = P_{yc} \quad (6)$$

The generator output power limits are expressed as follows:

$$P_i \leq P_i^+ \quad \forall P_i^+ \ll P_{yc} \quad \forall i = \overline{1, N} \quad (7)$$

The proposed model is established under the following assumptions: The transmission network is represented by an equivalent radial structure. Bus voltage magnitudes remain constant during dispatch calculations. Reactive power demand is negligible compared with active power demand. Transmission losses are dominated by line resistance. Generator ramp-rate constraints are

neglected. These assumptions allow the dispatch problem to be expressed in analytical form while preserving the dominant physical characteristics of transmission losses.

This indicates that the maximum output power of each generating source is significantly lower than the total load demand of the centralized electric vehicle charging station. In practical operation, each hydropower unit is also constrained by its generation limits. Therefore, the dispatch results obtained from the proposed analytical solution must satisfy the operating constraints of all generating units while ensuring the power demand of the EV charging station is supplied reliably.

Here, P_{yc} represents the total power demand required by the EV charging stations, which must be met by the small and medium hydropower plants.

From (6), it follows that:

$$P_N = P_{yc} - (P_1 + P_2 + \dots + P_{N-1}) \quad (8)$$

Accordingly, the power loss associated with the N -th transmission line can be expressed as:

$$\Delta P_N = C_N P_N^2 = C_N \left(P_{yc} - (P_1 + P_2 + \dots + P_{N-1}) \right)^2 \quad (9)$$

By expanding (9), it can be expressed as:

$$\Delta P_N = C_N \left[P_{yc}^2 + (P_1 + P_2 + \dots + P_{N-1})^2 - 2P_{yc} (P_1 + P_2 + \dots + P_{N-1}) \right] \quad (10)$$

By substituting (10) into (5), it follows that:

$$\Delta P = \sum_{i=1}^N C_i P_i^2 = \sum_{i=1}^{N-1} C_i P_i^2 + C_N \left[P_{yc}^2 + (P_1 + P_2 + \dots + P_{N-1})^2 - 2P_{yc} (P_1 + P_2 + \dots + P_{N-1}) \right] \quad (11)$$

It should be noted that the objective function considered in this study focuses on minimizing transmission power losses rather than minimizing generation costs. Therefore, the proposed formulation is not fully equivalent to the conventional economic dispatch (ED) problem, where generator fuel cost functions are explicitly included in the optimization process. Instead, the proposed approach can be interpreted as a loss-aware power dispatch strategy, which is particularly suitable for distributed hydropower systems and renewable energy sources with relatively similar operating costs. Under such conditions, minimizing transmission losses can significantly improve overall energy utilization efficiency and reduce unnecessary power dissipation in the network.

Accordingly, the generation outputs P_i of the small and medium hydropower plants are optimally allocated to satisfy the power balance constraint in (6) while minimizing the total transmission power losses, as expressed in the following objective function:

$$\Delta P \rightarrow \min_{\{P_1, \dots, P_N\}} \quad (12)$$

Based on optimization theory [2], (12) is satisfied when:

$$\frac{\partial \Delta P}{\partial P_i} = 0, i = 1, 2, \dots, N-1 \quad (13)$$

By combining (13) and (11), a set of $(N-1)$ equations is obtained:

$$2C_i P_i + 2C_N (P_1 + P_2 + \dots + P_{N-1}) = 2C_N P_{yc} \quad (i = 1, \dots, N-1) \quad (14)$$

In matrix form, the $(N-1)$ equations in (14) can be represented as:

$$\begin{pmatrix} 2(C_1 + C_N) & 2C_N & \dots & \dots & 2C_N \\ 2C_N & 2(C_2 + C_N) & \dots & \dots & 2C_N \\ 2C_N & 2C_N & 2(C_3 + C_N) & \dots & 2C_N \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 2C_N & 2C_N & \dots & \dots & 2(C_{N-1} + C_N) \end{pmatrix} \begin{pmatrix} P_1 \\ P_2 \\ P_3 \\ \vdots \\ P_{N-1} \end{pmatrix} = \begin{pmatrix} 2C_N P_{yc} \\ 2C_N P_{yc} \\ 2C_N P_{yc} \\ \vdots \\ 2C_N P_{yc} \end{pmatrix} \quad (15)$$

Let us define:

$$A = \begin{pmatrix} 2(C_1 + C_N) & 2C_N & \dots & \dots & 2C_N \\ 2C_N & 2(C_2 + C_N) & \dots & \dots & 2C_N \\ 2C_N & 2C_N & 2(C_3 + C_N) & \dots & 2C_N \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 2C_N & 2C_N & \dots & \dots & 2(C_{N-1} + C_N) \end{pmatrix} \quad (16)$$

$$X = \begin{pmatrix} P_1 \\ P_2 \\ P_3 \\ \vdots \\ P_{N-1} \end{pmatrix} \quad (17)$$

$$B = \begin{pmatrix} 2C_N P_{yc} \\ 2C_N P_{yc} \\ 2C_N P_{yc} \\ \vdots \\ 2C_N P_{yc} \end{pmatrix}$$

Accordingly, the following equation can be written:

$$AX = B \quad (18)$$

From (18), the solution X can be obtained as:

$$X = A^{-1}.B \quad (19)$$

Remark 1: Difference from Classical economic dispatch

It should be emphasized that the objective function considered in this paper minimizes transmission power losses only. Therefore, the proposed formulation differs from the conventional economic dispatch problem, in which generation cost functions are included. The method can be interpreted as a loss-minimization dispatch strategy applicable to distributed renewable generation systems with comparable operating costs.

Remark 2: Invertibility of matrix A

The invertibility of matrix A is guaranteed when all loss coefficients C_i are positive and mutually independent. Numerical conditioning may deteriorate if several coefficients become nearly identical. Nevertheless, for practical transmission systems with different line lengths and resistances, matrix A remains well-conditioned.

Thus, by solving the linear system in (18), the solution in the form of (19) is obtained.

Combined with (8), this enables the determination of the optimal power allocation for small and medium hydropower plants to meet the demand of EV charging stations while ensuring system balance.

Compared with the approach presented in reference [1], the proposed method provides an explicit and direct analytical solution for determining the generation outputs without requiring iterative optimization variables or intermediate updating procedures.

The proposed model is developed under the following assumptions: radial equivalent transmission structure, balanced three-phase operation, constant bus voltage magnitude, negligible reactive power contribution, and no generator ramp-rate constraints. Therefore, the proposed formulation is primarily intended for fast dispatch calculations in distributed hydropower systems.

3. SIMULATION STUDIES

3.1. Comparison with conventional dispatch methods

Compared with iterative approaches such as lambda iteration and iterative quadratic programming solvers, the proposed method computes generator outputs directly through an explicit matrix solution. This avoids iterative updates and can reduce the computational burden, suggesting potential for real-time implementation. Table 1 below presents a qualitative comparison of the methods.

Table 1. Comparison of iteration requirements and computational burden of economic dispatch methods.

Method	Iterative	Computational burden
Lambda iteration	Yes	Medium
Quadratic Programming	Yes	High
Proposed Method	No	Low

3.2. Discussion

To validate the proposed algorithm, this paper considers a cluster of small and medium hydropower plants, in which the generation sources are connected to a common point through transmission line branches. The lengths of these branches are referenced from the Power Development Plan VIII, including: Nậm Ôn 5 – Điện Biên (22 km), Mộc Châu – Trung Sơn hydropower interconnection (35 km), and Nậm Ôn 7 – Lai Châu (65 km). The system is assumed to operate at a regional voltage level of $U = 22$ kV. The transmission lines use ACSR 330/43 conductors with an approximate resistance of 0.0869 (Ω/km). Accordingly, the resistance of each transmission branch is determined based on its length as follows:

$$r_1 = 22 \times 0.0869 = 1.912\Omega \quad (20)$$

$$r_2 = 35 \times 0.0869 = 3.042\Omega \quad (21)$$

$$r_3 = 65 \times 0.0869 = 5.649\Omega \quad (22)$$

It is assumed that the total power demand of the EV charging stations is $P_{yc} = 700$ MW.

Based on (3), the corresponding coefficients C_i can be determined as:

$$C_1 = \frac{1.912}{(220 \times 10^3)^2} = \frac{1.912}{22^2 \cdot 10^8} = 3.95 \cdot 10^{-11} \quad (23)$$

$$C_2 = \frac{3.042}{22^2 \cdot 10^8} = 6.29 \cdot 10^{-11} \quad (24)$$

$$C_3 = \frac{5.649}{22^2 \cdot 10^8} = 11.67 \cdot 10^{-11} \quad (25)$$

According to (16), the matrix A can be expressed as:

$$\begin{pmatrix} 2(C_1 + C_3) & 2C_3 \\ 2C_3 & 2(C_2 + C_3) \end{pmatrix} = \begin{pmatrix} 31,24 \cdot 10^{-11} & 23,34 \cdot 10^{-11} \\ 23,34 \cdot 10^{-11} & 35,92 \cdot 10^{-11} \end{pmatrix} \quad (26)$$

The inverse of matrix A^{-1} is given by:

$$A^{-1} = \begin{pmatrix} 0,062 & -0,0405 \\ -0,0405 & 0,0541 \end{pmatrix} 10^{11} \quad (27)$$

Accordingly, the vector B can be expressed as:

$$B = \begin{bmatrix} 1400,11,67 \cdot 10^{-11} & 10^6 \\ 1400,11,67 \cdot 10^{-11} & 10^6 \end{bmatrix} = \begin{bmatrix} 16,34 \\ 16,34 \end{bmatrix} 10^{-5} \quad (28)$$

Accordingly, the solution X based on (19) can be expressed as:

$$X = A^{-1} \cdot B = \begin{pmatrix} 0,062 & -0,0405 \\ -0,0405 & 0,0541 \end{pmatrix} \begin{pmatrix} 16,34 \\ 16,34 \end{pmatrix} 10^{-5} = \begin{pmatrix} 355,9 \\ 223,7 \end{pmatrix} 10^6 \quad (29)$$

Therefore,

$$\begin{aligned} P_1 &= 355.9 \text{ MW} \\ P_2 &= 223,7 \text{ MW} \\ P_3 &= [700 - (353 + 224)] \cdot 10^6 = 120,4 \text{ MW} \end{aligned} \quad (30)$$

In addition, the authors carried out simulations under varying load demand conditions, where P_{yc} ranged from 200 MW to 600 MW, in order to validate the accuracy and reliability of the proposed method. However, for large-scale systems, the computation of the inverse matrix A^{-1} requires the numerical techniques presented in reference [4].

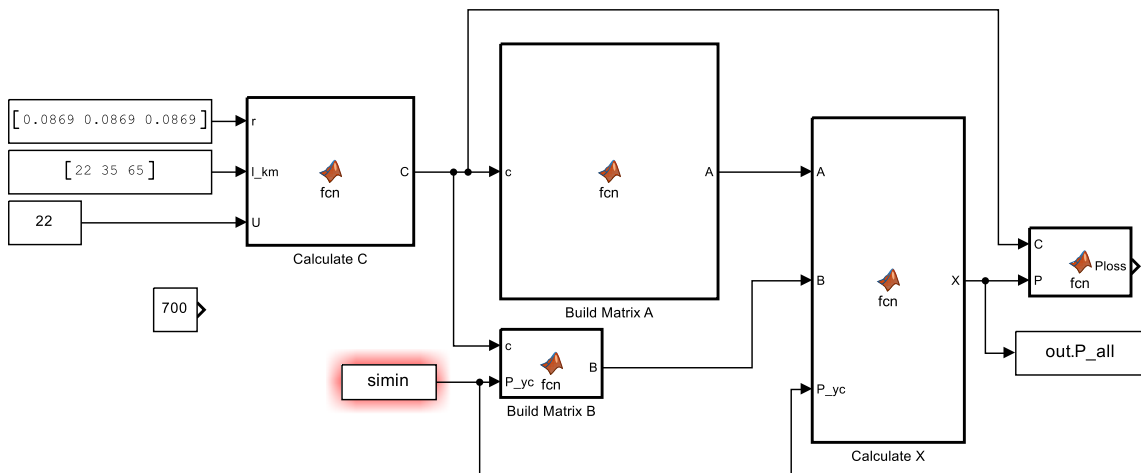


Figure 1. Matlab/Simulink implementation of the proposed power dispatch method for EV charging station systems with transmission line losses considered.

The results presented in Figure 2, which agree well with the analytical solutions in (29) and

(30), confirm that the proposed model accurately captures the fundamental principle of power dispatch, where generation units with lower loss coefficients C_i are assigned higher output levels. This validates that the proposed method achieves consistency with both economic objectives and the physical characteristics of the power system.

The simulation results demonstrate that generators associated with smaller transmission-loss coefficients are assigned higher output power. This behavior is consistent with the objective of minimizing transmission losses and confirms the physical validity of the proposed formulation.

Compared with conventional iterative optimization methods, the proposed approach offers several advantages: Explicit analytical solution. Reduced computational complexity. Easy implementation in Matlab/Simulink. Suitability for real-time dispatch applications.

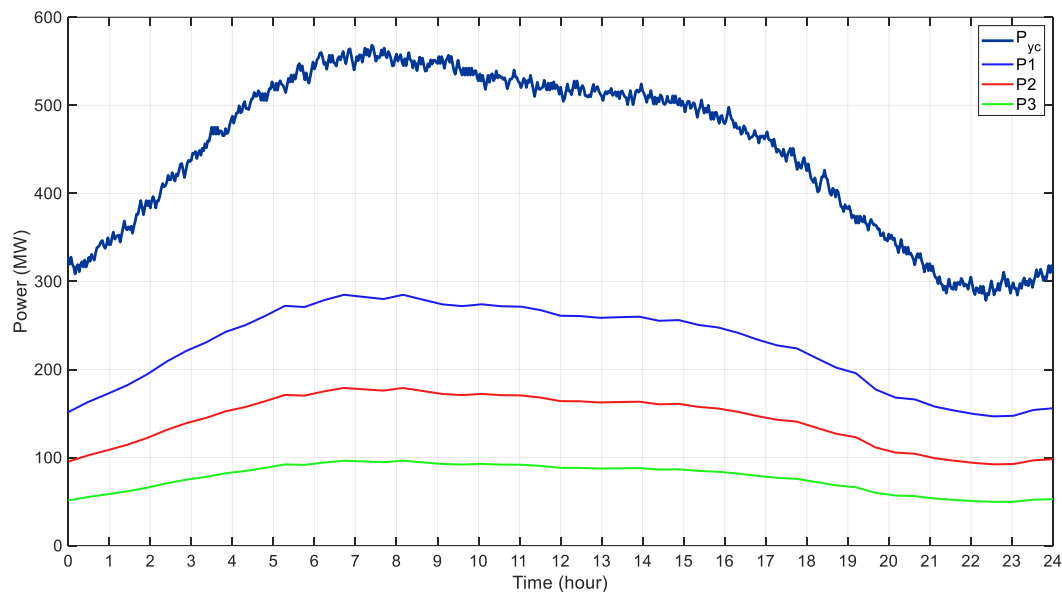


Figure 2. Simulation results of the 24-hour power dispatch under a time-varying load P_{yc} .

However, several limitations remain: Reactive power is neglected. Voltage constraints are not considered. Generator cost functions are omitted. The network topology is simplified into an equivalent radial structure.

Future research will focus on extending the formulation toward full economic dispatch and optimal power flow problems.

4. CONCLUSIONS

This paper proposed a transmission-loss-aware power dispatch algorithm for small and medium hydropower plants supplying EV charging stations. By introducing source-dependent loss coefficients into the dispatch formulation, an explicit analytical solution was obtained without relying on iterative optimization procedures.

Simulation results verified the effectiveness of the proposed approach under a 24-hour varying load profile. The obtained power allocation naturally prioritizes generation units with lower transmission losses, thereby improving energy delivery efficiency.

Compared with conventional dispatch approaches, the proposed method offers lower computational complexity and simpler implementation, making it suitable for real-time applications in distributed hydropower systems.

Future work will focus on incorporating generation cost functions, voltage constraints,

reactive power optimization, and multi-node network structures to establish a complete economic dispatch framework.

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TÓM TẮT

Xây dựng thuật toán xác định công suất phát cho các nhà máy thủy điện vừa và nhỏ cấp năng lượng cho các trạm sạc pin xe điện khi tính đến tổn thất đường dây

Bài báo này đề xuất một phương pháp điều độ công suất mới cho các nhà máy thủy điện vừa và nhỏ cung cấp điện cho các trạm sạc xe điện (EV), trong đó xét đến tổn thất công suất trên đường truyền tải. Khác với các phương pháp truyền thống, nơi tổn thất thường được xử lý thông qua các quá trình lặp hoặc các phép xấp xỉ, phương pháp được đề xuất tích hợp trực tiếp thành phần tổn thất vào mô hình điều độ thông qua các hệ số tổn thất phụ thuộc theo từng nguồn phát. Điều này cho phép phản ánh chính xác ảnh hưởng của khoảng cách truyền tải và đặc tính đường dây đối với từng tổ máy phát điện. Mặc dù đã có một số nghiên cứu xem xét tổn thất truyền tải trong bài toán điều độ kinh tế, nhưng vẫn còn rất ít nghiên cứu tập trung vào việc xây dựng nghiệm giải tích tường minh cho các hệ thống thủy điện phân tán cấp điện cho các trạm sạc xe điện. Khoảng trống nghiên cứu này là động lực thúc đẩy việc phát triển phương pháp phân bổ công suất có xét đến tổn thất được đề xuất. Một đóng góp quan trọng của nghiên cứu là xây dựng được nghiệm tường minh nhằm xác định công suất phát của các nguồn mà không cần sử dụng các thuật toán lặp phức tạp, qua đó cải thiện đáng kể hiệu quả tính toán. Phương pháp được kiểm chứng thông qua mô phỏng trên Matlab/Simulink với phụ tải biến thiên theo thời gian trong chu kỳ 24 giờ. Kết quả cho thấy phương pháp đạt độ chính xác cao và vận hành ổn định, trong đó các nguồn phát có hệ số tổn thất nhỏ hơn sẽ được ưu tiên huy động công suất. Các kết quả nghiên cứu chứng minh rằng phương pháp đề xuất không chỉ giúp giảm thời gian tính toán mà còn nâng cao tính thực tiễn vật lý của mô hình điều độ, phù hợp cho các ứng dụng thực tế trong các hệ thống thủy điện phân tán tích hợp hạ tầng sạc xe điện.

Từ khóa: Phân bổ công suất; Thủy điện; Tổn thất đường dây; Trạm sạc xe điện; Nguồn phân tán.