Analysis of Economic Load Dispatch for a Power System Network

Abdullah Al Mahfazur Rahman and Md.Fahimul Islam

***Abstract*—**A conventional power system network operates with many generating units with different capacities and objective functions. However, it is very imperative to run the network with the minimum cost. The cost minimization of the plant is possible to attain by the optimization techniques. The Economic load dispatch is an optimization technique, which gives an economical condition to the generation and distribution control network. Through the ELD, a power network can select the units of the power plants for supplying the power to the demand side while satisfying all the equity and inequity constraints. There are many conventional approaches to resolve ELD problems, like lambda iteration, linear programming, and dynamic programming methods, etc. This paper demonstrates the lambda iteration method under two different conditions, which are the transmission system without loss and with loss. For analysis, five generating units are taken into consideration with different objective functions and generation limits. The simulation is conducted in MATLAB. The simulation results reflect that the lambda iteration a fast converging method for the reduction of generation cost of a power network. This method also maintains the specified generation limits of the participating generating units.

***Keywords*—**Economic load dispatch (ELD), Optimal load dispatch, Unit commitment (UC), Incremental Fuel Cost, Transmission loss.

I. Introduction

THE demand for electricity throughout the world increases regularly. To meet this increasing demand, different conventional and nonconventional generating units are integrated with the power grid. In this perspective, the operation of a power network with minimum generation cost is one of the very important principles that can be achieved by optimal load dispatch. Using the optimal dispatch process the load demand can be addressed at a minimum cost [1]. The economic load dispatch is considered as one of the very effective optimal dispatch techniques to fulfill the load demand satisfying minimum generation cost [2]. ELD supports the power system to operate economically with proper generator scheduling. The objective of ELD is to indicate optimal planning of the generator's load demand to get maintaining minimum generation cost under certain constraints of the system [3],[4]. Economic load dispatch not only distributes the generated electricity to the load in an efficient way but also maintain other constraints within the limit. The generated electric energy cannot be stored in a bulk unit; it must serve the load on a real-time basis also meet the demand of variable loads. To meet the real-time demand it would require multiple numbers of generation units [5]. It is desirable to serve the power to the demand side at a minimum cost. This is why the ELD problems are considered as the basic problems of the power system [6]. Economic load dispatch does not consider the transmission system limitation. The main goal of this technique is not to indicate which generating unit to turn ON/OFF. It is a short-term technique to calculate the optimal operation of generating units in an economical way within a certain generation and transmission constraints. Earlier, the generator's cost curves were considered as continuous and monotonic. Afterward, it was found that it was an inaccurate assumption. For that, the objective function generated revenue loss. However, through ELD a highly constrained and nonlinear problem can optimize the profit return on capital investment. This nonlinear constraints problem can be optimized by various optimization techniques. There are many conventional techniques like the lambda iteration method, Newton-Raphson method, linear programming, and dynamic programming technique to solve ELD problems [7].

The goal of this paper is to demonstrate an ELD technique to reduce the generation cost for the power network consisting of multiple numbers of generation units. For the analysis and simulation of ELD the lambda iteration method is considered because of its easy handling capability of the generation limits. Moreover, using the lambda iteration method the non-

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convex ELD problems with transmission loss can be solved as an approximate convex problem [8]. For the compensation of losses, the penalty factor is considered in this method. Besides, the convergence rate of this method is very high compare to other methods.

The proceeding parts of the paper are arranged as follow: section II represents general concepts of ELD, the problem formulation of ELD is given in section III, algorithm is explained in section IV, the problem statement of ELD is given in section V, the simulation result is explained in section VI and finally, the paper is concluded in section VII.

II. General Concert of ELD

In economic load dispatch, the real and reactive power of the generators is maintained at a certain operating limit to fulfill the load demand with minimum cost. To serve the cumulative demand the number and size of power plant units are increasing where the generating units are connected in parallel with the increasing power network [9]. In the grid-connected system, it is desirable to operate the generation unit economically [10]. The economic load dispatch ensures the optimal scheduling of different generator units by creating a different combination of generating units for meeting the load demand [11]. The ELD problems can slave in two ways: one line load dispatch and unit commitment procedure [12]. To reduce the total power supply in the online load dispatch system the load of the system is distributed among the parallel generator units. On the other hand, in the unit commitment system, the loads are assigned to those units that have been considered as the low-cost units [13].

A. Load Dispatch with Optimal Planning

The optimal planning of load dispatch includes the proper use of energy sources under certain constraints, where the power transfer occurs maintaining the safety of the system with the uninterrupted power supply to the consumers at a minimum price. To provide power at minimum cost the influential features of the units are:

- The Operating efficiencies of the power units
- The power loss due to the transmission system
- The fuel cost

B. Incremental Fuel Cost

Consider the quadratic from [14], where the fuel cost of generators is given by,

$$C_i = \alpha_i + \beta_i P_i + \gamma_i {P_i}^2 \quad (1)$$

The derivative of the fuel cost gives the incremental fuel cost is $\boldsymbol{\lambda}$ as,

$$\frac{dC_i}{dP_i} = 2\gamma_i P_i + \beta_i = \lambda \quad (2)$$

The incremental fuel cost indicates the price of fuel for the next unit of generated power [14]. The cost of labor and maintenance are also included in the incremental fuel cost [15].

III. Problem Formulation of ELD

The economic dispatch problem is formulated under two different behaviors of the transmission network. Initially, it is considered that the generators are connected to the load bus where the transmission loss is neglected. Later on, transmission system loss is considered for the solution of the problem.

A. ELD without Transmission loss

Consider N_g is the number of supply units connected to the grid where the demand at the receiving is P_D, the per-unit cost of each selected generating unit is C_i. In ELD, the goal is to reduce the total generation cost and the objective function C_T is,

$$C_T = \sum_{i=1}^{N_g} C_i = \sum_{i=1}^{N_g} (\alpha_i + \beta_i P_i + \gamma_i {P_i}^2) \quad (3)$$

If the transmission loss of the system is neglected then the system constraint is,

$$\sum_{i=1}^{N_g} P_{Gi} = P_D \quad (4)$$

With generation limit as the equality constrain, the output power of individual generating unit is expressed as,

$$P_{Gi(min)} \leq P_{Gi} \leq P_{Gi(max)} \quad (5)$$

Now, this constrain optimization can be solved by the Lagrange function, which is

$$\mathcal{L} = C - \lambda(\sum P_{Gi} - P_D) \quad (6)$$

The minimum value of this unconstraint problem can be found at the point where the derivative of $\mathcal{L}$ with respect to P_i and $\boldsymbol{\lambda}$ equals to zero i.e.,

$$\frac{\partial \mathcal{L}}{\partial P_i} = 0 \quad (7)$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = 0 \quad (8)$$

The equation (6) expresses the output power of individual generation unit as,

$$P_{Gi} = \frac{\lambda - \beta_i}{2\gamma_i} \quad (9)$$

Moreover, the power deviation of the system is calculated using the following equation

$$\Delta P^{k} = P_D - \sum_{i=1}^{N_g} (P_{Gi})^{k} \tag{10}$$

According to [14], equation (4) represents an equity constraint that has to satisfy. For a system without transmission loss and generation limits, all the contributing power units should run at the value of **λ** while satisfying the equality constraint given by (10). Using equation (9) and (4) an analytical solution of **λ** is written as,

$$\lambda = \frac{P_D + \sum_{i=1}^{N_g} \frac{\beta_i}{2\gamma_i}}{\sum_{i=1}^{N_g} \frac{1}{2\gamma_i}} \tag{11}$$

and,

$$\Delta\lambda^{(k)} = \frac{\Delta P^{(k)}}{\sum_{i=1}^{N_g} (\frac{1}{2\gamma_i})} \tag{12}$$

B. ELD with Transmission loss

Conventionally, the generating units of the thermal power plant are connected to the load bus with the help of a transmission network. So for that type of configuration ELD problem solution is slightly complicated than the previous system with no transmission loss. Because in this system we have to consider the transmission loss. For the system considering transmission loss,

$$\sum_{i=1}^{N_g} P_{Gi} = P_D + P_L \tag{13}$$

With a similar generation limit as given in equation (5). According to [14], if a transmission loss function is considered as,

$$P_L = \sum_{i=1}^{N_g} B_{ii} (P_{Gi})^2 \tag{14}$$

The output of individual generation unit is written as,

$$P_{Gi}^{k} = \frac{\lambda^{(k)} - \beta_i}{2(\gamma_i + \lambda^k B_{ii})} \tag{15}$$

The real power deviation is calculated using the following equation,

$$\Delta P^{k} = P_D + P_L^{k} - \sum_{i=1}^{N_g} P_{Gi}^{(k)} \tag{16}$$

The process continues until the ΔP^{k} is less than a specified value. Using equation (14) and (15), the incremental fuel cost is calculated as,

$$\Delta\lambda^{(k)} = \frac{\Delta P^{(k)}}{\sum_{i=1}^{N_g} (\frac{dP_{Gi}^{k}}{d\lambda})} \tag{17}$$

IV. Algorithm of Economic Load Dispatch

The algorithm of the Lambda iteration method is explained under two different conditions of the system which are :

A. Algorithm without Transmission loss

Step-1: Read the values of the total number of the generators N_g, cost coefficients (α_i,β_i and γ_i), minimum and maximum power limits ($P_{Gi(min)}$ and $P_{Gi(max)}$) and load side power requirement P_D.

Step-2: Start with a reasonable value of λ.

Step-3: Using equation (9) and calculate the generated power P_{Gi} for each unit.

Step-4: Check the generation limits:
if, $P_{Gi} > P_{Gi(max)}$, set $P_{Gi} = P_{Gi(max)}$
if, $P_{Gi} < P_{Gi(min)}$, set $P_{Gi} = P_{Gi(min)}$

Step-5: Calculate the power deviation ΔP using equation (10).

Step-6: If ΔP is less than error ε then stop the operation execute the results
Otherwise, go to the next step,
Set, λ = λ − Δλ if, ΔP is greater than 0
Set, λ = λ + Δλ if, ΔP is less than 0

Step-7: Repeat same the technique from Step-3 until the iteration converges.
The flowchart of the economic load dispatch is given in fig.1.

B. Algorithm with Transmission loss

Step-1: Read the values of total number of the generators,N_g, cost coefficients (α_i,β_i and γ_i), minimum and maximum power limits ($P_{Gi(min)}$ and $P_{Gi(max)}$) and load side power demand, and transmission loss P_L).

Step-2: start with a reasonable value of λ.

Step-3: Calculate the generated power P_{Gi} for each unit using equation (15).

Step-4: Check the generation limits:
if $P_{Gi} > P_{Gi(max)}$, set $P_{Gi} = P_{Gi(max)}$
if $P_{Gi} < P_{Gi(min)}$, set $P_{Gi} = P_{Gi(min)}$

Step-5: Calculate the power deviation ΔP using equation (16).

Step-6: If ΔP is less than error ε then stop the operation execute the results
Otherwise, go to the next step,
Set, $\lambda = \lambda - \Delta\lambda$ if, ΔP is greater than 0
Set, $\lambda = \lambda + \Delta\lambda$ if, ΔP is less than 0

Step-7: Repeat same the technique from Step-3 until the iteration converges.
The flowchart of the economic load dispatch is given in fig.2.

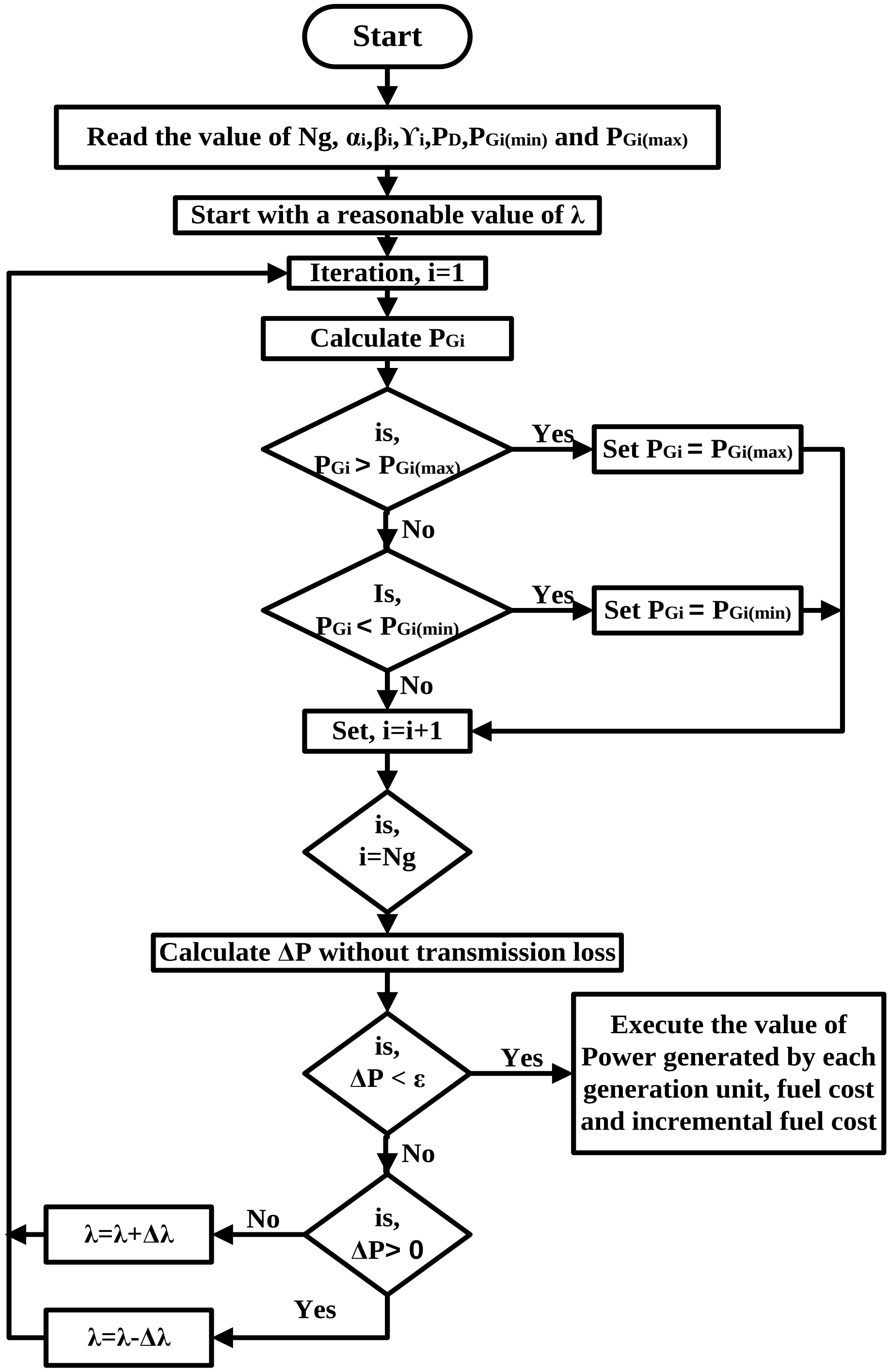

Fig. 1. ELD without transmission loss

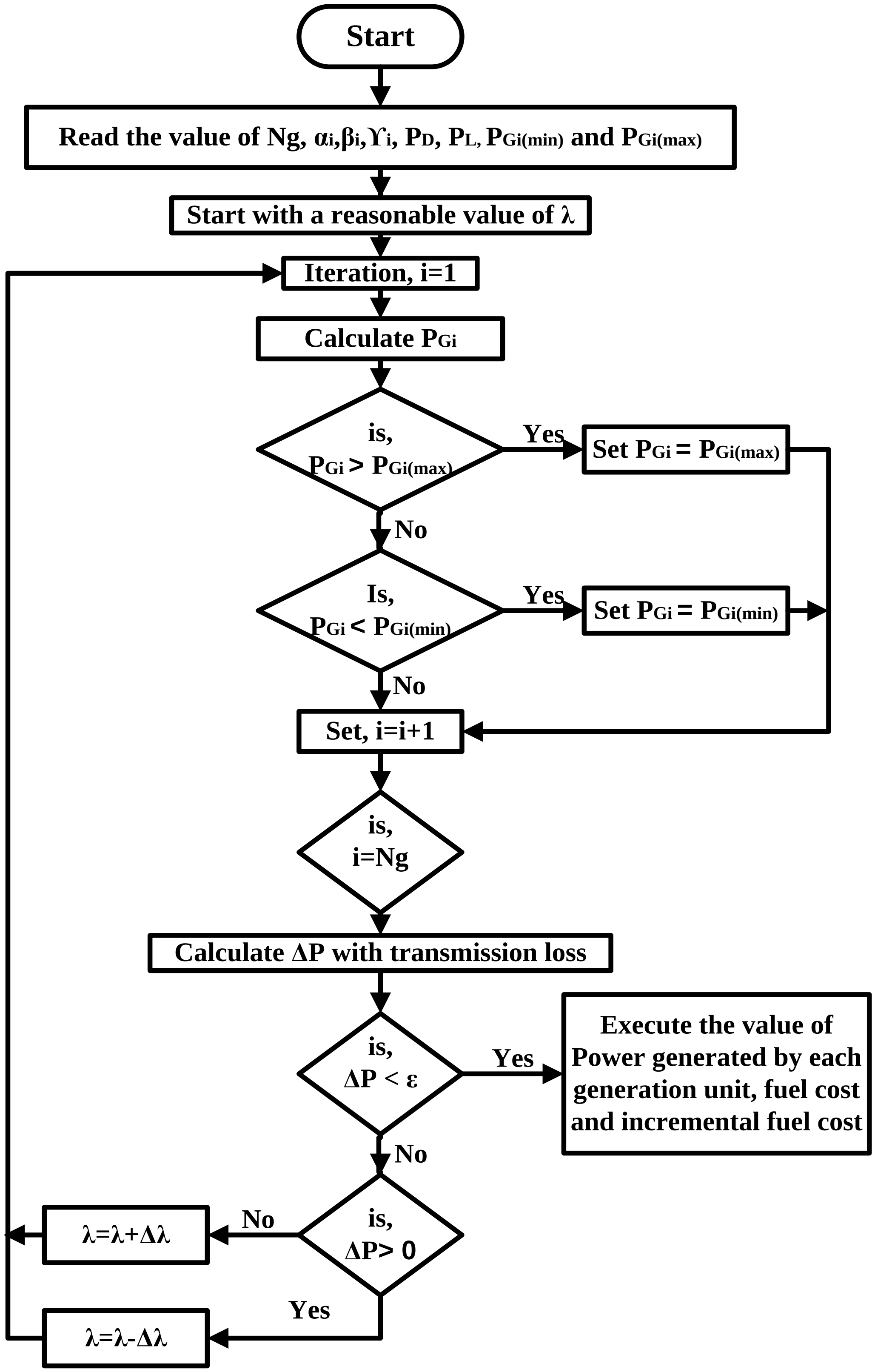

Fig. 2. ELD with transmission loss

V. PROBLEM STATEMENT OF ELD

To analyze the economic load dispatch two different cases are considered as,

Case-1: Economic Load Dispatch problem without transmission loss.

In this case, we have formulated a problem where the total Power Demand, P_D=1250MW, with no transmission loss and the objective function of different generation units are,

$C_1 = 425 + 5.5P_1 + 0.004(P_1)^2$ $/h,
$C_2 = 400 + 5.3P_2 + 0.006(P_2)^2$ $/h,
$C_3 = 350 + 5.6P_1 + 0.007(P_3)^2$ $/h,
$C_4 = 300 + 5.7P_4 + 0.007(P_4)^2$ $/h,
$C_5 = 200 + 5.4P_5 + 0.009(P_5)^2$ $/h,

The generation limits of the committing units are,

$200MW \leq P_1 \geq 400MW$
$150MW \leq P_2 \geq 350MW$
$100MW \leq P_3 \geq 425MW$
$150MW \leq P_4 \geq 350MW$
$100MW \leq P_5 \geq 225MW$

The tasks are to find the total generation cost, incremental fuel cost, and power generated by different generators with generation cost.

Case-2: Economic Load Dispatch problem with transmission loss.

In this case, all the generator's parameters are similar to the **Case-1**. However, the additional parameter is the transmission loss equation, which is,

$$P_L = 0.000210(P_1)^2 + 0.000205(P_2)^2 + 0.000185(P_3)^2 + 0.000177(P_4)^2 + 0.000186(P_5)^2$$

The tasks are to find the total generation cost, incremental fuel cost, transmission loss, and power generated by different generators with generation cost.

VI. RESULT ANALYSIS

The algorithms of economic load dispatch without transmission loss and transmission loss are implemented in the two cases explained in the previous section. The simulation is conducted in MATLAB. Results of both cases are:

Case-1: The simulation results for meeting the power demand of 1250MW are,

Total Cost = 10,417 $/h
Incremental fuel cost, $\boldsymbol{\lambda}$ = 8.4896 $/MWh

TABLE I
POWER GENERATED BY DIFFERENT WITHOUT UNDER NO TRANSMISSION LOSS

Unit	Power (MW)	Generation Cost per hour ($)
1	373.7	3038.9
2	265.8	2232.6
3	206.4	1804
4	232.46	1949.3
5	171.64	1392.2

In this case, the highest amount of power is shared by unit 1 and the lowest amount of power is shared by unit 5. TABLE I shows the optimal generation distribution of different units for an equal incremental fuel cost of 8.4896 $/MWh within their generation limits.

Case-2: The system simulation results for meeting the power demand of 1250MW are,

Total Cost = 11,040 $/h
$\boldsymbol{\lambda}$ = 9.7230 $/MWh
Transmission loss = 70MW

TABLE II
POWER GENERATED BY DIFFERENT UNITS WITH TRANSMISSION LOSS

Unit	Power (MW)	Generation Cost per hour ($)
1	349.48	2835.7
2	276.67	2325.6
3	234.29	2046.3
4	260.52	2192.2
5	199.98	1639.8

The distribution of generated power at equal incremental fuel cost 9.7230 $/MWh is given in TABLE II. As the transmission loss is considered in this case the overall generation cost and incremental fuel cost are increased significantly for delivering an equal amount of load. The amount of power generated by individual units has increased because the system has to deal with an additional loss of 70MW.

VII. CONCLUSIONS

The Economic Load Dispatch is considered one of the very efficient ways to reduce the generator's operating costs. In this paper, five generators base thermal stations are considered for the ELD solution using the lambda iteration method. Initially, it is considered that all the generators and loads are connected to a single bus where the transmission loss is neglected. In the latter case, the same generator's objective functions with generation limits have been introduced. Additionally, transmission loss is added in this case. From simulation results of both the cases, it is observed that all the generators can supply power to the load with their minimum cost and at the same time maintain their specified generation limits, which is one of the objectives of this paper. Moreover, using the Lambda iteration method, the iteration converges very quickly. Using this method, the low-cost solution of electricity generation is possible with the combination of generators having different objectives combinations and generation limits. The area of interest of this work is to optimize the generation cost of different thermal power plants. The environmental aspects like carbon emission can be added to the objective functions of the power units.

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