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Analysis of Economic Load Dispatch, For Generation Expansion Planning

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ABSTRACT

The idea to generate electricity at minimum cost for purpose of economic dispatch is a strong consideration for generating power operation and system planners in the power industry and utilities. The major cost of running generating power plants, is the fuel cost while other cost may be added to the fuel cost, the fuel cost ($/h) or (₦/h) which is a function of the power generation in (MW). The fuel cost curve required in this analysis is the parabolic curve function. The derivation of the cost-function evidently shows that the incremental fuel-cost curve, analysis of the slope of the fuel cost curve need to be minimized. The incremental fuel-cost curve indicates how expensive it will be to generate the next increment of power (MW). Therefore, simple operating cost for economic dispatch and coordination equation techniques were used and validated with Matlab application which shows the individual cost of operations for increment cost of each generating capacity (MW).

Keywords: Economic Analysis, Load Dispatch, Generation Expansion Planning, Cost-function, generating power operation

1. Introduction

The analysis of electricity utility is the largest and most complex industry in the world. The electrical engineer who dwell in searching for economic development for an economic load dispatch, for generation expansion planning will constantly encounter challenging problems to solve, in as much as energy generation, transmission and distribution are concerned. The analysis considered the economic allocation of power generation, the economic load dispatchable generators which is based on the necessary conditions for minimization, application of coordination equation are employed to the incremental cost of generating plant using (Lamda) for the determination of cost coefficients. Therefore, the day to day growth is power system due to energy demand has made the power system: generating transmission and distribution an optimization problem to solve. The idea of unbounding the power system will in strong term encourage significantly the efficiency of the electricity utility, is a way to manage and monitor the activities of load dispatch programs.

2. Analysis and Method

The analysis of economic allocation for power generators on the same bus (in the case of lossless lines).

Suppose we would like to minimize the total cost of generation supplying a load demand P_D.

– Now to minimize the total cost of generation is given as:

$$C_t = \sum_{i=1}^{ng} C_i = total\ \cos t \tag{1}$$

or where; $C_i = \alpha_i + \beta_i p_i + \gamma_i p_i^2$ (2)

$$C_t = \sum_{i=1}^{ng} \left(\alpha_i + \beta_i p_i + \gamma_i p_i^2 \right) \tag{3}$$

Subject to the constraint:

$$\sum_{i=1}^{ng} P_i = p_D \tag{4}$$

The analysis is shown in figure 1.0 that is the number of 'dispatchable generator' is *ng*, while the total number of generators is *n*. This evidently means that $(n–n_g)$ generators are not subject to economic allocation, they may probably be on flat load, example nuclear power generators), may reached their maximum or minimum limit of generations).

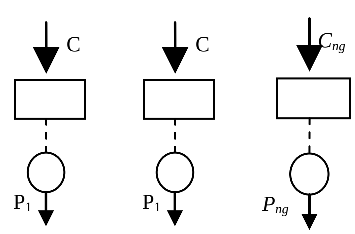

Fig. 1.0: Economic load dispatchable generators.

Therefore, the function, f is given as:

$$f = C_t + \lambda\left(p_D - \sum_{i=1}^{ng} P_i\right) \quad (5)$$

If the necessary condition is minimum then we have:

$$\frac{\partial f}{\partial p_i} = 0 \quad (6)$$

and

$$\frac{\partial f}{\partial \lambda} = 0 \quad (7)$$

This evidently mean that, equation (5) becomes:

$$f = \sum_{i=1}^{N}\left(\alpha_i + \beta_i p_i + \gamma p_i^2\right) + \lambda\left(p_D - \sum_{i=1}^{ng} P_i\right) \quad (8)$$

Then, the first condition:

$$\frac{\partial c_t}{\partial p_i} + \lambda(0-1) = 0 \quad (9)$$

The total cost, C_t is given as:

$$C_t = C_1 + C_2 + C_3 + ... + C_{ng} \quad (10)$$

This mean that differencing the above equation above:

$$\frac{\partial c_i}{\partial p_i} = \frac{\partial c_i}{\partial p_i} = \lambda \quad (11)$$

That is, the partial derivative of the total cost c_t, to the ratio of the partial derivative of the generator (power p_i) is constant, to the total derivative of the cost of the ratio of power, p_i .

Thus, the condition for optimal dispatch is given as:

$$\frac{\partial c_i}{\partial p_i} = \lambda,\ i = 1,2,3....,ng \quad (12)$$

From equation (3) and (8); we have:

$$\frac{\partial c_t}{\partial p_i} = \beta_i + 2\gamma_i p_i \quad (13)$$

where: $\frac{\partial c_i}{\partial p_i} = \lambda$ (12)

This means, that:

$$\lambda = \beta_i + 2\gamma_i p_i \quad (14)$$

or

$$\lambda - \beta_i = 2\gamma_i p_i \quad (15)$$

$$p_i = \frac{\lambda - \beta_i}{2\lambda_i} \quad (16)$$

Rearranging the equation, further:

$$\sum_{i-1}^{ng} \frac{\lambda - \beta_i}{2\gamma_i} = p_i \quad (17)$$

Similarly, for 2nd condition for equality constraints:

$$\sum_{i-1}^{ng} \frac{\lambda - \beta_i}{2\gamma_i} = p_D$$

or

$$\sum_{i-1}^{ng} p_i = p_D \quad (18)$$

Thus, solving for the incremental cost (λ), which in actual sense indicate how expensive it will be to generate the next increment" of power.

Simplifying again further we have:

$$\sum_{i-1}^{ng}\left(\frac{\lambda_i}{2\gamma_i} - \frac{\beta_i}{2\gamma_i}\right) = p_D \quad (19)$$

Therefore, the coordination equation (16) becomes:

$$p_i \frac{\lambda - \beta_i}{2\gamma_i} \quad (16)$$

Assuming that, there is no limits on generation, no losses, then we can have the most economical state of operation: This is when all the plants have the same incremental cost λ, and their total generation equals to load demand.

This evidently mean that the incremental cost (λ) for optimal generation can be obtained since generation of power for optimal operations depend on the incremental cost (λ).

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Simplifying equation (19) again in order to solve for (λ):

$$\sum_{i-1}^{ng}\left(\frac{\lambda_i}{2\gamma_i}-\frac{\beta_i}{2\gamma_i}\right)=p_D \qquad (19)$$

or

$$\sum_{i-1}^{ng}\left(\frac{\lambda_i}{2\gamma_i}\right)=p_D+\frac{\beta_i}{2\gamma_i} \qquad (20)$$

or

$$\lambda\sum_{i-1}^{ng}\left(\frac{1}{2\gamma_i}\right)=p_D+\frac{\beta_i}{2\gamma_i} \qquad (21)$$

or

$$\lambda=\frac{P_D+\sum_{i-1}^{ng}\frac{\beta i}{2\lambda_i}}{\sum_{i-1}^{ng}\left(\frac{1}{2\gamma_i}\right)} \qquad (22)$$

Since, the value of incremental cost λ, are determined we can now recalled equation (14):

$$\lambda=\beta_i+2\gamma_i p_i \qquad (14)$$

Thus, $\lambda-\beta_i=2\gamma_i p_i$ (23)

or

$$p_i=\frac{\lambda-\beta_i}{2\gamma_i} \qquad (24)$$

p_i = the power to be generated

λ = incremental cost

consumption coefficient (α,β,γ)

Case 1:

In the case of lossless power systems, that is, generators on a common bus, the analytical solution are valid for optimal dispatch problems.

Case 2:

Similarly, where losses are significant and the generators are geographically dispersed, then the solution cannot be found analytically. In such cases an iterative solution are considered or valid.

Case 3:

Consider a system for a lossless system, where the iterative process are formulated.

- Apply the gradient – method to solve the optimization problem by iteration.

Recalled equation (24):

$$p_i=\frac{\lambda-\beta_i}{2\gamma_i} \qquad (24)$$

- the constraint equation becomes:

$$f(\lambda)=\sum_{i-1}^{ng}\frac{\lambda\beta_i}{2\gamma_i}=p_D \qquad (25)$$

If $p_i=P_D$

(26)

We can invoke, the Maclaurin's and Taylor's Series expansion: for Maclaurin's series; is really a special case of Taylors series:

That is,

Maclaurin's series:

$f(x)=f(0)+x.f'(0)+\frac{x^2}{2!}f''(0)+.....$ express as a function in terms of its differential coefficients at $x=0$ at the point k.

That is,

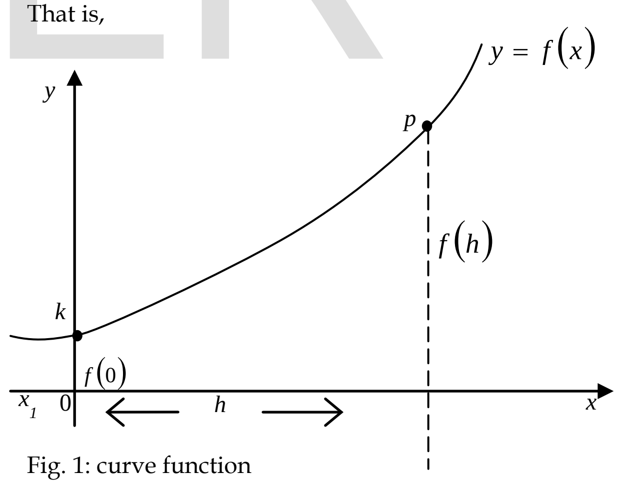

Fig. 1: curve function

At point *p*,

$$f(h)=f(0)+h.f'(0)+\frac{h^2}{2!}f''(0)+\frac{h^3}{3!}f'''(0)......... \qquad (28)$$

Similarly, if we move the y – axis a – unit to the left, then the equation, relative to the new axis now becomes:

$$y = f(a+x) \quad (29)$$

That is the value @ k is now $f(a)$.

Consider the fig.2,

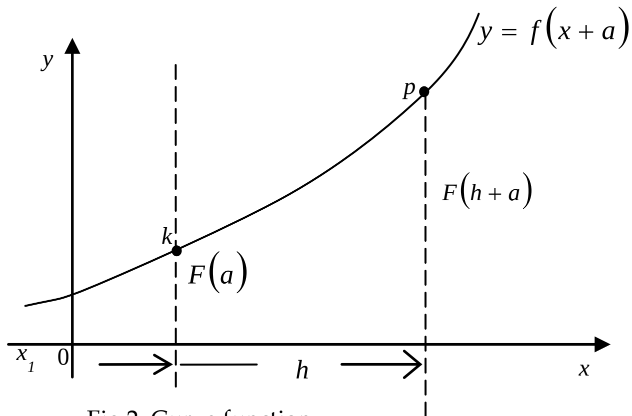

Fig 2: Curve function

From fig. 2, we can now generate the Taylor's series expansion as:

If $a = x$, then

$$f(x+h) = f(x) + h.f'(x) + \frac{h^2}{2!} f''(x) + \frac{h^3}{3!} f'''(x)\text{.........} \quad (30)$$

This is the Taylor's series expansion.

Taking the first –order terms of the Taylor series expansion about the point $\lambda^{(k)}$ = which gives us:

$$f(\lambda)^k + \left(\frac{df(\lambda)}{d\lambda}\right)^{(k)} \Delta\lambda^{(k)} = P_D \quad (31)$$

where:

$$\frac{df(\lambda)}{d\lambda} = f',\ \Delta\lambda = h \quad (32)$$

or

from (31):

$$f(\lambda)^k - p_D = \left(\frac{df(\lambda)}{d\lambda}\right)^{(k)} \Delta\lambda^{(k)} \quad (33)$$

Multiply through by –ve: that is

$$\left.\begin{aligned} -f(\lambda)^k + p_D &= -\left(\frac{df(\lambda)}{d\lambda}\right)^{(k)} \Delta\lambda^{(k)} \\ &\text{or} \\ p_D - f(\lambda)^k &= -\left(\frac{df(\lambda)}{d\lambda}\right)^{(k)} \Delta\lambda^{(k)} \end{aligned}\right\} \quad (34)$$

or

$$(\Delta\lambda)^k = \frac{p_D - f(\lambda)^k}{\left(\frac{df(\lambda)}{d\lambda}\right)^{(k)}} \quad (35)$$

But,

$$f(\lambda)^k = \sum_{i=1}^{ng} p_i^{(k)} = \sum_{i=1}^{ng} \frac{\lambda - \beta_i}{2\gamma_i}$$

Recalled, equation (35):

$$\Delta\lambda^{(k)} = \frac{p_D - \sum_{i=1}^{ng} p_i^{(k)}}{\left(\frac{df(\lambda)}{d\lambda}\right)^{(k)}} \quad (37)$$

if: $p_D - \sum_{i=1}^{ng} p_i^{(k)} = \Delta p^{(k)}$ (38)

or

$$\Delta\lambda^{(k)} = \frac{\Delta p^{(k)}}{\left(\frac{df(\lambda)}{d\lambda}\right)^{(k)}} \quad (39)$$

if: $pf(\lambda) = dp_i^{(k)}$ (40)

and

$$\Delta\lambda^{(k)} = \frac{\Delta p^{(k)}}{\sum\left(\frac{dp_i}{d\lambda}\right)^{(k)}} \quad (41)$$

or

$$\Delta\lambda^{(k)} = \frac{\Delta p^{(k)}}{\sum \frac{1}{2\gamma_i}} \quad (42)$$

Thus, the error(s) correction is given as:

$$\lambda^{k+1} = \lambda^{(k)} + \Delta\lambda^{(k)} \quad (43)$$

where

$$\Delta p^{(k)} = p_D - \sum_{i=1}^{ng} p_i^{(k)}$$

- evidently, the iteration now continued till $\Delta p^{(k)}$ is smaller or converges than a specified accuracy.
- that is starting a flat – condition with a value: $\lambda^{(1)}$, which is used to start the iteration. Hence an algorithms are outlined to follow the processes as:

Step 1: Assume an initial value for Landa (λ), that is : $\lambda^{(1)}$

Step 2: Using the formulated equation: $p_i^1 = \dfrac{\lambda^{(1)} - \beta_i}{2\lambda_i}$

Compute all the power (p_i) for the first iterate.

Step 3: check, if the summation of powers, p_i equals the demand p_D, and find the difference between them thus:

$$\Delta p^{(1)} = p_D - \sum_{i=1}^{ng} p_i^{(1)}$$

that is, if the difference is smaller than the specified accuracy, a solution is reached, otherwise continue.

Step 4: Compute the changes in the incremental cost (λ) :

$$\Delta\lambda^{(1)} = \frac{\Delta p^{(1)}}{\sum \frac{1}{2\gamma_i}}$$

Compute and continue the second estimate for λ, that is

$$\lambda^{(2)} = \lambda^{(1)} + \Delta\lambda^{(1)}$$

Step 5: Observe the procedure until a repeated process till step 3, in the algorithms indicates convergence.

%Graphical Demonstration

```
axis([0 450 6.5 10.5]);
lambda=8.5;
p1=250:10:450;
p2=150:10:350;
p3=100:10:250;
IC1=5.3+0.008*p1;
IC2=5.5+0.012*p2;
IC3=5.8+0.018*p3;
px = 0:100:400;
plot(p1, IC1, p2, IC2, p3, IC3, px, lambda*ones(1,
length(px)), '-m');
xlabel('P MW'), ylabel(' $/MWh'), grid
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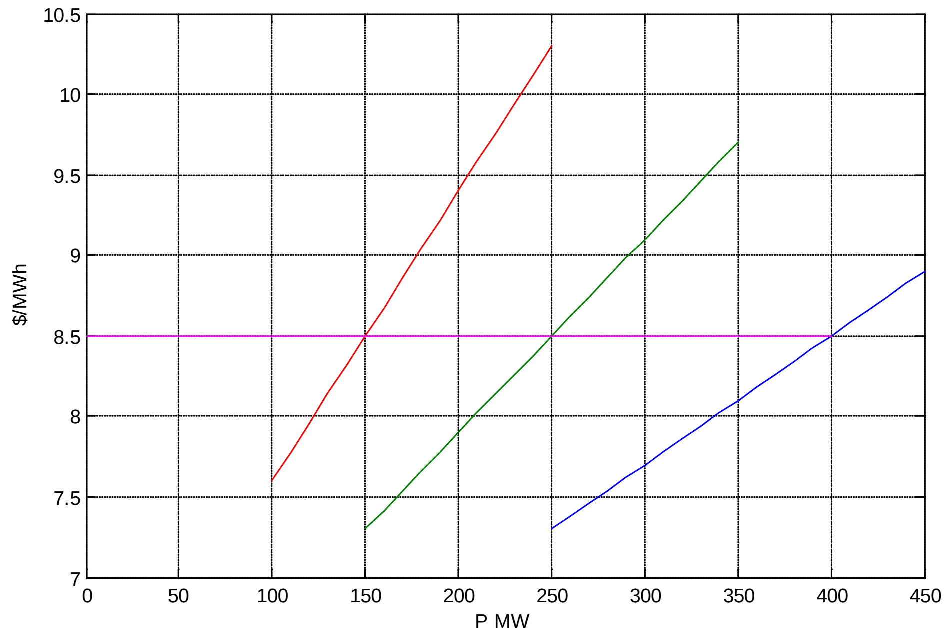

Conclusion

The economic load dispatch problem for generation expansion planning is a major concern to the economy, which need to be addressed at all time, because of the overlapping problems of generation, transmission and distribution scenarios. Analysis of simple economic load dispatch algorithms are formulated to strongly look at some of the challenges areas, in the direction of driving an economic benefit for load dispatch for generation capacity expansion.

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