Cost Minimization of Power System Generation Using Artificial Neural Network (ANN)

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ABSTRACT
Attempts to generate electricity at a minimal cost or economic dispatch (ED) are a problem for many operators in the power industry. The activities involved are very complicated, evolves in time by unpredictable events. Currently the application of Artificial Intelligence methods in this industry has produced tremendous positive results. In this regard, this study developed Rivann software to provide the best load distribution for optimal power generation with minimal fuel cost using artificial neural network (ANN). The approach is validated by using the lagrangian multiplier method. Result obtained from Rivpann show daily cost saving or Netsave derived from optimal distribution of load as against equal distribution of load. The system will assist operators in thermal power plants with the task of planning power generation economically. The result obtained from the application also explains the important role intelligent support systems can play in the management of the electricity generation industry.

Keywords: Artificial Intelligence, Minimizing cost of generation, Artificial Neural Network, Economic Dispatch, Lagrangian multiplier method, decision support software.

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1. INTRODUCTION
Rapid growth in power system industry has made the issue of optimization in power generation, distribution and transmission to become very significant. In the very recent time, deregulation in power industry has changed the part played by various units in the electricity industry for efficiency reasons [1]. Services provided by electric power vendors which originally used to be one single entity are now unbundled into three different entities: production, transmission and distribution. The service providers’ compete in providing good electricity delivery and at the same time strive to make profit. To maintain efficiency, security and reliability of supply are not compromised otherwise customer interest and protection will not be guaranteed. In other to achieve these, best practices in economic dispatch [2] are employed. The objective of ED is to systematically seek the lowest cost of electricity production that will be consistent with electricity demand. To minimize cost, ED will increase the use of more efficient generating unit and at the same time address three issues of concern - better fuel usage, reduce maintenance cost and reduced greenhouse gas emission [3, 4, 5], that would result from less efficient generation. Economic dispatch therefore seeks to minimize the total cost of generating power (production cost) at various stations while satisfying the loads and the losses in the transmission lines.
Computer applications as decision support tool (DSS) can be used to provide fair and consistent decisions, and at the same time it can improve the effectiveness of decision making process [6]. A DSS Application as an approach for supporting decision making is typically built for solution of a certain problem or to evaluate an opportunity. It is based on this fact that this paper presents a decision support system Rivpann that uses artificial neural network method to reduce cost during electricity generation process.

Many solution techniques have been proposed and also available to solving economic dispatch problem with varied degree of successes. They can be divided into two main categories, the algorithmic mathematical solution and artificial intelligent solution as reported in several literatures. Among the algorithmic solutions are Interior point (IP) algorithm [7], Simplex algorithm (SA), Quadratic programming (QP), and Dynamic programming (DP) [8]. Lagrange relaxation method (LRM) [9, 10], linear programming (LP), Non-linear programming (NLP) and Newton-based methods have also been reported. These methods failed to solve Optimal Power flow problems because most iteration converge slowly, have difficulty in detecting infeasibility, tendency to error due to linear approximation of non linear estimates and high computational complexity of solution due to large sparse linear system. As a result they converge at sub optimal solutions or to local minima. But currently proposed Artificial Intelligent optimization methods based on heuristics and operational research presented by researchers have emerged with global optimum solution for power system optimization. They include Expert system (ES), Ant Colony search (ACS) [11], Simulated annealing (SA) [12], Artificial Neural networks (ANN) [13, 14, 15, 16, 17], Fuzzy logic (FL) [18] and Genetic Algorithm (GA) [19]. Others include Meta heuristic methods such as Tabu search (TS) [20], Particle swarm optimization (PSO) [21] and Evolutionary programming (EP) [22].

Application of these methods depends on the researchers' area of interest as each method has its own advantages and disadvantages; and notably ANN has proved to be very efficient in solving complex problems because of its properties of robustness, fast computation, non linear modeling and learning ability.

2. PROBLEM STATEMENT

In most developing countries there is persistent power outage mainly due to high cost of electricity production. Standard of living in these countries is generally poor because the per capita consumption of electricity is low. Nigeria for example, with a per capita consumption of less than 136 kWhour; is almost the lowest in sub-Sahara Africa. The good news is that the application of the principles of ED would enhance electricity generation and would improve infrastructural development. This approach also need to be delivered in a simple and user friendly manner to enable operators effectively apply it. Based on these considerations, Rivpann, a decision support software application that would provide informed decision on minimal cost of electricity production is presented.

3. ED FORMULATIONS

Generally, power system can be operated optimally if the principles of equal incremental cost rate are applied to the problem of optimal distribution of loads among the various stations forming a power pool [23]. The most precise way to describe such operation is to use the relation between the input and output characteristics as available from the generation data of the individual generators.

The characteristic of this relation is described mathematically as:

\[ I = a + bP + cP^2 + dP^3 + \ldots + nP^n \]

where I is the input(cost of fuel) and the output P (power produced by generator) with coefficients a, b, c to n. Alternatively, it can be represented graphically as shown in Fig 1.

Fig 1: Input - Output characteristic of a generator.
I₀ in Fig 1 represents the amount of input required to keep the generator functioning when there is no load. The slopes of the curve at various load-points give the incremental rate characteristic. If I₁ and I₂ are the inputs corresponding to the loads P₁ and P₂ respectively, the increase in input required for meeting the increase of load from P₁ to P₂ is given by:

$$I_2 - I_1 = \int \frac{dI}{dP} \ \text{d}P$$

The area under the curve between P₁ and P₂ is the incremental rate. Similarly, from no load to P₁, the increase in input I₁ = I₀ is given by the area under the incremental rate curve from P = 0 to P₁. R₁ is the incremental rate. By differentiating the expression in equation 1 (stopping at the third power), we obtain the incremental rate characteristic as:

$$R_i = \frac{dI}{dP} = b + 2c(P) + 3d(P^2)$$

3.1 Generation Cost Minimization

The objective of generation cost minimization is to schedule generation such that input (I) is minimum for the given total power P, subject to restriction that sum of P_k = P is the total load received, where P_k is the output of unit k. Using the lagrangian method if

$$f\left(P_1, P_2, \ldots, P_n\right) = 0$$

And

$$\sum_{k=1}^{n} P_k - P = 0$$

Then

$$\sum_{k=1}^{n} P_k = P$$

Apparent Power (P) = \sqrt{\left(\text{active power}\right)^2 + \left(\text{reactive power}\right)^2}

If I represent the cost of input, the minimum input cost is realized when

$$\frac{dI}{dP_k} = 0 \quad \text{where} \quad I = \sum_{k=1}^{n} I_k \quad I_k = \text{total input}$$

Applying lagrangian type multiplier where

$$I = I_k - \lambda f \quad \lambda = \text{lagrangian type of multiplier}$$

$$\frac{dI}{dP_k} = \frac{dI_k}{dP_k} - \lambda \frac{df}{dP_k} = 0$$

Where f is the function of total power received ie

$$f\left(P_1, P_2, \ldots, P_n\right) = 0 \quad \text{or} \quad \sum_{k=1}^{n} P_k - P = 0$$

But RHS

$$\frac{dI}{dP_k} - \lambda \frac{df}{dP_k} = 0$$

$$\Rightarrow \frac{dI}{dP_k} = \lambda$$

Hence

$$\frac{dI}{dP_k} = \lambda \quad \text{................................................................................(3)}$$

The incremental cost of input to kth unit in Naira per MW hour is equal to the incremental cost of the received power. The equation (6) may be rewritten as:

$$\frac{dI_1}{dP_1} = \frac{dI_2}{dP_2} = \frac{dI_3}{dP_3} = \cdots = \frac{dI_n}{dP_n}$$

If the incremental rate of kth unit in written as R_k, then

$$R_{i_1} = R_{i_2} = R_{i_3} = \cdots = R_k = \cdots = R_{i_n} = \frac{\lambda}{C_{i_1}} = \frac{\lambda}{C_{i_2}} = \frac{\lambda}{C_{i_3}} = \cdots = \frac{\lambda}{C_{i_k}} = \cdots = \frac{\lambda}{C_{i_n}} \quad \text{...............................................................................(8)}$$

Using symbol, C, for incremental production cost in Naira per MW hour then:

$$C_{i_1} = C_{i_2} = C_{i_3} = \cdots = C_{i_k} = \cdots = C_{i_n} = \lambda$$

$$\lambda$$, - the lagrangian multiplier - is the incremental cost of received power in Naira/MW hour.

3.2 Artificial Intelligence Solution:

With the increasing demand for power, power system network continues to expand; control of energy management system becomes more complex. Parameter of the new power system network introduces additional complexity and these results to discontinuity. To sort for solution, in most cases, the lemma ‘divide and conquer’ is applied to efficiently solve the complex problem through decomposition of simpler elements. Solution to these elements when combined together forms the solution to the complex system. In the last decade, traditional power system computation uses AI methodologies to decompose problems into various functions performing task. Although many AI methods are being used in power system operation, ANN has received more attention.
This is because of its clear model, easy implementation and good performance. Precisely, the technique involved in ANN-based methods does not require explicit models to represent the complex relationship between the various factors that determine the problem [13, 15]. Only parametric data in respect of the problem (which may historical or online) are needed. ANN with its parallel architecture can approximate any continuous function due to its robustness, and fault tolerance capability [16]. ANN models are proven to be superior to other empirical regression models.

3.2.1 The Neural Model

In general, suppose we consider the case of a five-bus power system network in a one line diagram as shown in Fig 2. The five-bus power system network consists of three generator buses (P_{G1}, P_{G2}, P_{G3}) and two load buses (P_{D3} and P_{D4}). A computer based application for the optimal distribution cost using artificial neural network solution can be developed based on the above background information. For the task of minimizing the input cost of generating power for the model we begin with the specification of the neural network parameters (in this case historical) as follows:

**Input parameter**

C_s -- Cost of fuel (gas) in Naira/mmscf per day for all the generators.

**Output Parameter**

P_r -- Total output power/load in MW per hour serviced by the generators per day.

A neural model for the operation of the station generators is shown in Fig 3. The input parameters C1 to Cs are cost of fuel used by the three generators in Fig 2. The Pr is total output power produced by the combined three generators to service a load. This specification will propagate the input parameters (cost) through the network to the output. During this process the network learns (neural learning) with different inputs and the weight(chg wght) values are changed dynamically until their values are balanced (output equals target) or the error (MSE = d) is minimal or zero. The activation function (Obj fxtn) is sigmoid and the learning algorithm is back propagation. Table 1 shows the historical data for the operation of the five-bus network. The table contains data of generator input cost as C1, C2, C3, while P1, P2, P3, are power generated data for P_{G1}, P_{G2}, and P_{G3} generators respectively for the five-bus network in fig 2. It is derived based on the fuel input and power output of the polynomial of equation (3).
Table 1: Sample of Output Power and Cost of Input in Naira Per Hour

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3.2.2 Specification of the Neural Architecture

The Network architecture usually describes the number of layers in a network, the number of neurons in each layer, each layer’s transfer function, and how the layers are connected to each other. The best architecture depends on the type of problem to be represented by the network. The architecture employed in the above neural model is multilayer feed forward network with one hidden layer. The performance function (MSE) is given by:

$$MSE = \frac{1}{N} \sum_{i=1}^{N} (y_i - \alpha_i)^2$$

Network functions are determined by connections between elements. Learning for a particular function is by adjusting the values of the connections (weights) between elements. The sigmoid activation function is given by:

$$\sigma(x) = \frac{1}{(1 + e^{-x})}$$

The back propagation learning algorithm updates the network weights and biases in the direction in which the performance function decreases most rapidly – the negative of the gradient. Each one of the iteration is of the form:

$$x_{k+1} = x_k - \alpha_k g_k$$

where

$$X_{k+1}$$ = vector of the next weight iteration, $$X_k$$ = a vector of current weight and biases ,

$$\alpha_k$$ = learning rate, $$g_k$$ = current gradient.

Based on the data in table 1 the neural architecture for the five-bus network is shown in fig 4. The input and output parameters are also stated as for the neural model.
Input Parameters for the Model:
C(s) - Total fuel cost Consumed by the station per generator

Output Parameters for the Model:
P(r) - Total output power/Load demand

4. RESULTS

Results obtained from ‘Rivpann’ decision support application are shown in table 2 for various load demands. Expectedly the difference between operating the station optimally as against equal distribution is clearly identified in the table as NetSave. The daily cost saving (NetSave) for each of the load demands per day is also shown. The table 2 also shows result of optimal load scheduling (OPS) for various load demands. This provides operators with information on how to allocate loads for optimal operation.

<table>
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<td>Gen3</td>
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<td>973.088</td>
<td>1107.18</td>
<td>1109.421</td>
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</table>

| NetSave | 1625.568 | 1213.752 | 4922.466 | 5076.134 |

<table>
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Key: EQD = Cost of Equal Distribution of load: L1, L2, L3, L4 = load demand: OPD = Cost of Optimal Distribution of load: OPS = Optimal Scheduling of load per generator

Fig. 4: Neural Architecture
5. DISCUSSIONS

For the theory of incremental rate to apply it is assumed that the following conditions would exist:
(a) Input - output curves are continuous
(b) first derivatives of the input - output curves are continuous
(c) Value of the incremental rate increases with the increase in output

In the analysis of optimal load division between the various units of a plant, it is expected that the available historical data on cost is absolutely correct. The implementation of the ‘Rivpann’ program is based on data set for the test cases of table 1. The input cost function is derived from equation 3 with all coefficients positive. (The coefficients for input cost equations are obtained using Matlab Curve Fitting Toolbox). The DSS software was formulated using artificial neural network method and developed as an interactive application for operators at gas turbine generating (GTG) plant. The design uses a special object oriented methodology feature of MatLab called handle graphics technology (HGT).

This approach provides menu-driven guides that would enable operators with little knowledge of computer to navigate through the application without difficulty. Each set of input parameter is stored in an excel file to avoid error while entering data. Line plots of cost versus power output are shown in fig 3. The optimum economy is achieved if every unit (i.e. \(P_{g1}\), \(P_{g2}\), and \(P_{g3}\)) operates at the same incremental cost (IC). At any point on the incremental cost, the three generators are operated optimally and fuel utilization is seen to be less. Neural output of simulation in plot and numerical values, daily cost saving and network performance plot derived from Rivpann application are shown in fig 5 and fig 6. The output of daily net saving per load demand when multiplied by 30 days will give the cost savings per month.

6. CONCLUSION

Minimizing cost of fuel in generating electricity is a real world problem and requires practical solution. This paper presented Rivpann decision support application tool designed to determine the best combination of power generating plant to produce electricity with less fuel cost. The small difference in error when compared with the lagrangian multiplier method can be ignored due to network compensation. Robustness and fault tolerance are qualities of this approach over the lagrangian method. Simulation data from other stations tested on Rivpann show no significant difference in result implying that the system can be deployed in a dissimilar geographical location.

7. RECOMMENDATIONS FOR FUTURE DEVELOPMENT

Rivpann can be extended to include an embedded form. When interfaced with a sensor can automatically control the switching of power plant for optimal operation. Additional testing data with varying load for each power output data case can also be simulated. Data for a short duration load and load demand located beyond the protection zone need to be included in the network training as well. The location of a load data plays important role in the power trip decision.

8. CONTRIBUTION TO KNOWLEDGE

This shows that power system optimization by using neural network is possible in Nigeria. The Rivpann software application developed here is the first of its kind because of its strict analytical formalism. Currently, this is the only application in power system industry that has applied the standard concepts of Lagrangian Multiplier theory and Artificial Neural Network techniques in the Economic analysis of Power generation.
Fig. 5 Sample screen for the neural network ED with training plot inserted.

Fig. 6: Sample screen for the Neural network ED with output of simulation in plot and numerical values, daily cost saving and network performance plot.
REFERENCES


Author’s Brief

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