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ECONOMIC OPERATION OF REAL POWER SYSTEM UNDER DIFFERENT CONTINGENCIES

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ABSTRACT

Economical and reliable operation of power system is very essential in electrical energy industry. Since the electrical energy industry should respond an follow the load pattern, so the quick and accurate response will be important. This work deals with a practical power system. The optimal power flow approach using Newton method is helpful in economic power system operation because it could take into consideration both the cost of generation and the power loss in the system. Intelligent technique is fast and accurate approach which can be used for this problem. Newton method were used to prepare the required Data to train back propagation Artificial Neural Network(ANN). The phase angle of the voltage at each bus bar was used as input data set because it can expresses an exact image of the power system. The results which are obtained by using such approach were fast and accurate, so this approach could be used for online economic operation.

Key Words: Power System, Economic Operation, Optimal Power Flow, Artificial Neural Network, Economic Dispatch, Cost Function.

Introduction

Electrical energy is at the heart of recent civilization. The industry of electrical energy is very complex. The production of such industry cannot be stored, and it should be available to the customers continuously at any time. Consequently, the electrical energy utilities should respond and follow the load pattern of the consumers no matter if it is day or night, summer or winter.
Electrical power systems are large-scaled and complex systems. The power system consists of different subsystems which are generation, transmission and distribution. Electrical power generated at power plant should be transmitted across long distances to the load.
The utilities of power systems look for an economical and reliable operation of power system
From an economical point of view, the main objectives are low cost generation and low losses during power transmission and distribution. To achieve these objectives the system should be monitored, studied and analyzed continuously. The monitoring and analysis need special tools to

get optimal results. These special tools could be considered as optimization problems, like optimal power flow, economic dispatch and unit commitment.

There are different formulations and techniques used for optimal power flow solution. Some researchers have used conventional optimization techniques while other researchers have used artificial intelligent techniques like Artificial Neural Network, Fuzzy Logic and Genetic Algorithms.

1.1 Statement of the problem

The real electrical power system is extremely complex and has many technical, economic and environmental constraints. It is a complex optimization to achieve the economic operation of the real power system.

The main goals for such complex optimization problem are to reduce the cost of production, achieve transmission minimum losses, and keep the system operating with acceptable technical criteria of bus voltage profile and thermal limitations of transmission lines.

The goal of this research is to study a real system which is a part of GCC power system. The practical research which looks for solutions of existing problems or improvement of the system operation is greatly required.

This work will study the system under different operation conditions of load and contingencies using conventional optimization solutions and artificial intelligent approaches. It will present the economic way which the system can be operated.

1.2 Significance of the study

The research will study the real power system which is part of the GCC interconnected power system. Practical power systems need continuous monitoring and collection of data for analysis and improvement.

Such system will be studied and analyzed with different contingencies to achieve economic operation and maintain the technical criteria of the system.

1.3 scope and limitation

The main limitation of this work may be the updated data of recent time operation conditions.

1.4 Conceptual Frameworks

In this research work, practical data will be collected for a considerable period. These data will be used to develop cost functions of the power plants, as well as the constrains of the system.

Different mathematical models will be used to solve the optimization problem to choose the optimal solution for economic operation of the system. Intelligent system will be developed as well.

2. Literature review

Optimal power flow was introduced by Carpentier as a nonlinear programming optimization problem of economic dispatch of power system [1].

There are different formulations used for optimal power flow solution. Some of the researchers were criticized because they didn't take into consideration the requirement of practical real-time applications [2]. A research project which was proposed by Wibowo, R.S et al. adopted Adaptive

Neuoro Fuzzy Inference System to determine the penalty factor in the losses of transmission lines to achieve economic dispatch of electrical power system[3].

Kirmani et al. presented a novel approach to reduce the loss in distribution power system by using fuzzy techniques [4]. Prassana T.S et al. proposes two fuzzy stochastic algorithms to solve multi security constrained economic operation of power systems. The combination of fuzzy logic with evolutionary programming and Tabu search reveals accurate results[5]. Suman M et al. used back propagation neural network to solve the optimization problem of power generation dispatch[6].

Hari Om have presented Genetic algorithm technique to solve optimal power flow problem. Such algorithm was modeled to be suitable for any power system[7].

3. Methodology

The main part of variable cost of operation of fossil fuel units is the fuel, although there are additional variable costs like, spare parts, maintenance and salaries of the workers. The cost which will be considered are the cost which can be controlled during operation, i.e the cost which is a function of the power output of the generation units. The fixed cost will not be considered.

An empirical data will be used to get the relationship which defines the input cost of a generation unit (i), C_i in money unit/hour and the output power of the same generation unit P_i.

The input cost function will be

$$Ci = a_i P_i^2 + b_i P_i + c_i \quad \text{unit of money/hr}$$

This quadratic equation can be obtained by using least mean square curve fitting technique. The data will be taken from each power plant.

The incremental operating cost can be obtained for each unit by:

$$\lambda = \frac{dC_i}{dP_i} = a_i P_i + b_i \quad \text{unit of money/MWh}$$

If we have two units of different incremental costs supplying the load, the load could be transferred from the unit of higher incremental cost to the unit of lower incremental cost. The more efficient unit will be loaded more until the incremental cost will be the same, so this is the optimum operation point[2].

For N-number of units

$$\boldsymbol{C_T = C_1 + C_2 + C_3 + \cdots + C_N = \sum_{k=1}^{N} C_k} \qquad \textbf{………….(3)}$$

The total Power of the plant is P_T

$$P_T = P_1 + P_2 + \ldots\ldots P_N = \sum_{k=1}^{N} P_k \qquad \ldots\ldots\ldots\ldots (4)$$

The objective now is to minimize C_T for a given total power

$$dC_T = \frac{\partial C_T}{\partial P_1} dP_1 + \frac{\partial C_T}{\partial P_2} dP_2 + \cdots \frac{\partial C_T}{\partial P_n} dP_N \quad \text{....... (5)}$$

The supplied power is constant, so:

$$dP_T = dP_1 + dP_2 + \ldots\ldots dP_N = 0 \quad \text{......... (6)}$$

Multiply equation (6) by λ and subtract from (5),

$$\left\{\frac{\partial C_T}{\partial P_1} - \lambda\right\} dP_1 + \left\{\frac{\partial C_T}{\partial P_2} - \lambda\right\} dP_2 + \cdots \left\{\frac{\partial C_T}{\partial P_N}\right\} dP_N \quad \text{.......... (7)}$$

This equality is satisfied when each quantity between brackets is zero.

$$\left\{\frac{\partial C_T}{\partial P_i} - \lambda_i\right\} = 0 \qquad i = 1, \ldots \ldots, N \quad \text{........... (8)}$$

Since only C_i of C_T varies with P_i, then the partial derivative will be full derivative,

$$.\ \lambda = \frac{dC_1}{dP_1} = \frac{dC_2}{dP_2} \ldots \ldots = \frac{dC_N}{dP_n} \quad \text{.............(9)}$$

Since it is not always that all the units are in operation. Some of them may be off for maintenance. Some of the units run as spinning reserve in the system.

The power generation limits will be considered as inequality constraints.

$$P_{min,i} \leq P_i \leq P_{max,\,i} \qquad i = 1, \ldots\ldots N \quad \text{............... (10)}$$

P_{max} is the maximum generation capacity of the unit, and P_{min} is the minimum power generated by the unit while the boiler thermal components are stabilized according to the design.

In the practical electric power system, the transmission losses should be taken into considerations and assumed as apart of the load supplied. Then equation(4) should be modified as:

$$P_T = P_1 + P_2 + \ldots\ldots P_N - P_{Loss} \quad \text{..........(11)}$$

Where P_{Loss} is the total transmission line losses. But PT is constant, So

$$0 = dP_1 + dP_2 + \ldots\ldots dP_N - P_{Loss} \quad \text{..................(12)}$$

In equation (12) P_{Loss} includes the power loss of every unit,

$$dP_{Loss} = \frac{\partial P_{Loss}}{\partial P_1} dP_1 + \frac{\partial P_{Loss}}{\partial P_2} dP_2 + \cdots . \frac{\partial P_{Loss}}{\partial P_N} dP_N \quad \text{.............(13)}$$

As given in equation (5) the maximum power generation means $dC_T=0$. Multiply (12) and (13) by λ;

$$0=\left(\lambda\frac{\partial P_{Loss}}{\partial P_1}-\lambda\right)dP_1+\left(\lambda\frac{\partial P_{Loss}}{\partial P_2}-\lambda\right)dP_2+\cdots\ldots\left(\lambda\frac{\partial P_{Loss}}{\partial P_N}-\lambda\right)dP_N \quad \ldots..(14)$$

Adding (14) with (5)

$$0=\sum_1^N\left\{\frac{\partial C_T}{\partial P_i}+\lambda\frac{\partial P_{Loss}}{\partial P_i}-\lambda\right\}dP_1 \quad \ldots\ldots(15)$$

Equation (15) satisfies when:

$$\left\{\frac{\partial C_T}{\partial P_i}+\lambda\frac{\partial P_{Loss}}{\partial P_i}-\lambda\right\}=0 \qquad i=1,\ldots\ldots,N \quad \ldots\ldots(16)$$

$$\frac{\partial C_T}{\partial P_i}=\frac{dC_T}{dP_i} \qquad i=1,\ldots\ldots N$$

$$.\ \lambda=\frac{\partial C_1}{\partial P_1}L_1=\frac{\partial C_2}{\partial P_2}L_2=\cdots\frac{\partial C_N}{\partial P_N}L_N \quad \ldots\ldots(17)$$

Li is penalty factor of the load (i). It is:

$$L_i=\frac{1}{1-\partial P_{Loss}/\partial P_i} \qquad i=1,\ldots\ldots,N \quad \ldots\ldots(18)$$

If the area has N units, The generated power will be:

$$P=[P_1 \quad P_2 \ \ldots\ldots\ldots .P_N]^T \quad \ldots\ldots(19)$$

Then the loss of transmission will be

$$P_{Loss}=P^TBP \quad \ldots\ldots(20)$$

Where B is:

$$B=\begin{bmatrix} B_{11} & B_{12} & \cdots & B_{1N} \\ B_{12} & B_{22} & \cdots & B_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ B_{1N} & B_{2N} & \cdots & B_{NN} \end{bmatrix}$$

Bij are called loss coefficients. Loss coefficient could be taken as constant for simplification in practical problems.

4. Results and Discussion

The practical system which is studied in this work is described as follows:-

The system is part of GCC interconnected Network with two voltages (115Kv and 13.8 Kv). It contain 24 different busses, 42 different branches (30 transmission lines and 14 transformers), and 5 generators[1].The generators of such system are fossil fuel units. They are connected to the bus bars (1,2,3,4, and 17).

Artificial Neural Network technique will be adopted to solve Economic operation problem of the practical power system which was described before. The statistics of the monthly energy production (in Mega Watt hour) and the operating cost of each power station are collected for one year (2013). Such data was used to get the Cost function of each power station. MATLAB Curve fitting toolbox was used to get the Cost functions. The cost functions of the power stations (in unit of money/hour) are:

$$C_1 = 0.006P_1^2 + 7.7P_1 + 204$$

$$C_2 = 0.0095P_2^2 + 11P_2 + 200$$

$$C_3 = 0.008P_3^2 + 8.7P_3 + 221$$

$$C_4 = 0.009P_4^2 + 8.7P_4 + 200$$

$$C_{17} = 0.0085P_{17}^2 + 13P_{17} + 180$$

Newton Optimal Power Flow algorithm was used for analytical solution of this practical power system. Transmission losses are taken into consideration. Loads of the different buses, active and reactive, were changed randomly as could be happen in the practical systems. Different contingencies were simulated on the system to obtain a good image about the system when it operates in different normal and abnormal conditions.

The results show that power station at bus (17) is the most expensive one in the system. Such case is expected because this power station is really old and the efficiency is low. This work kept the minimum generation of such station at 50 MW which the load needed for special purposes, even though it is not the most optimal cases. Such conclusion was proven by changing the minimum generation setting for this power station. Table-1 represents base case optimal solution of the system. The plan to change the units of this power station by a new more efficient and modern unit has been started.

Table(1)

Power Station (bus number)	Generation (MW)
1	465.1664
2	103.5376
3	273.3422
3	186.3390
17	50.000

Artificial Neural Network(ANN) is adopted as intelligent technique which is useful in these kinds of applications. Electrical power system is a complicated system. So the data which will be generated is not linearly separable, which leads us to use multilayer neural network[10].

The voltage phase angle at each bus are taken as input matrix while the optimal generation of each power station are taken as output matrix for training, validation and testing. The voltage phase angle is taken as input matrix because reflects the real image of the system's behavior much better than using the real load at each bus which was done by researchers[6]. For example if there is any contingency in the system the real load at the buses will not changed while the optimal generation will be changed. In case of voltage phase angle, it will change when there is any contingency in the system. Therefore it will be more useful to train and generate accurate ANN as shown later.

Thirty different scenarios were implemented on the system to get the data which are needed for neural network. MATLAB Neural Network Toolbox was used to build the neural network. Back propagation with Levenberg-Marquardt algorithm (trainlm) was used efficiently to train the neural network. Data are divided randomly as follows:

Training=70%= 20 samples.

Validation=15%=5 samples.

Testing =15%= 5 samples.

The algorithms used for training, performance and data division are shown in Fig. 1. Epoch, Time, Performance, Mu, Gradient and Validation Check are shown in Fig. 2.

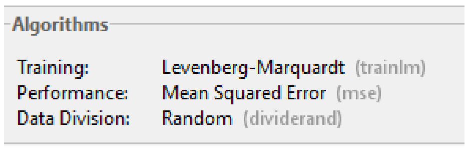

Fig. 1

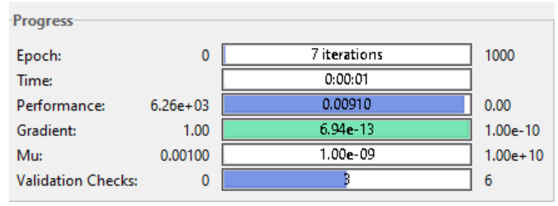

Fig. 2

Performance plot is shown in Fig. 3. Regression plot of Training, Validation and test are shown in Fig4.

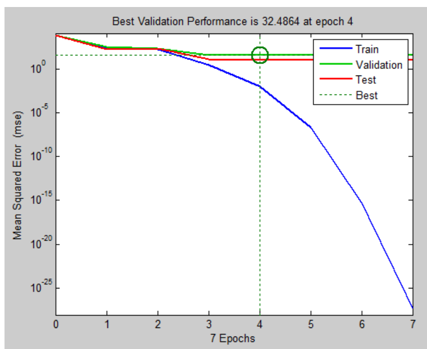

Fig. 3

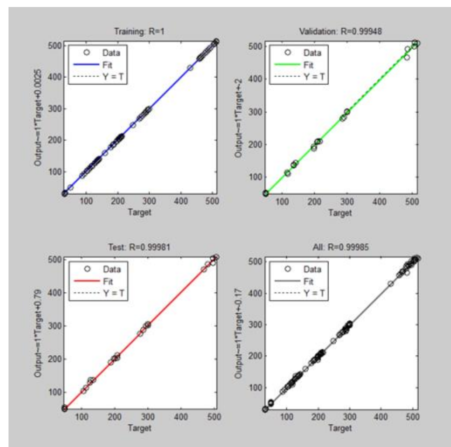

Fig. 4

The Regression Index (R) is one or very close to one which means that there is almost perfect relationship between input and output. The values of (R) is give in table-2

Data	R- value
Training	1
Validation	0.99948
Testing	0.99981
All	0.99985

Therefore the decisions which can be taken by the artificial neural network will be accurate and trusted. The trained ANN is shown at Fig. 5. It can be used as an efficient online decision maker tool for economic operation of power system, but phase measuring unit (PMU) should be installed in each bus bar to measure the voltage phase angle.

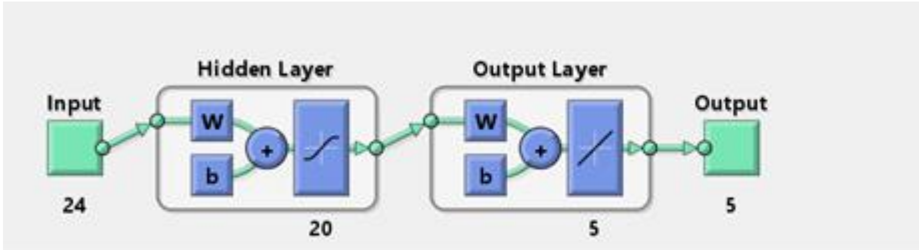

Fig. 5

5. Conclusion

It has been found that that optimal approach is useful in operation of practical power system economically. Newton optimal power flow is very efficient to solve the optimization problem of electrical power system taking into consideration the all the technical constraints in power system like voltage profile and thermal limitations of the transmission lines. This analytical tool could be used to generate data set for training ANN to be used by dispatch centers of practical power system. Multilayer neural network has been adopted because of the complexity of the power system which produce non linearly separable data.

The research showed that the operation of the power station at bus bar 17 is really expensive and uneconomical. The results and the performance of the ANN revealed that the bus voltage angles is very good choice which can be adopted as input matrix for the neural network because it could be affected by any change in the power system. The regression results were quite good as well.

The important recommendation is to stop the power station at bus 17 or replace the old units by efficient new units. The second proposal is adopted.

ANN is quite efficient and fast approach which can deal with economic operation of power system and can online.

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