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A Fuzzy Logic Approach to solve Unit Commitment and Economic Dispatch Problem

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Abstract: Unit commitment optimization for the scheduling of units and effective load sharing among thermal units is extensively used in electrical power system planning. The target of unit commitment optimization will be economical when the criteria is to test the best combination of thermal units to serve the load with the optimium load sharing among units satisfying various constraints like load demand, voltages limits, power generations, spinning reserves within defined range and minimize operating cost without effecting the system. An approach for solving unit commitment based on the Lagrangian Algorithm and Fuzzy Logic has been proposed for the optimal scheduling of thermal units. Lagrange algorithm is based on equal incremental cost curve technique and widely used in different environments where other conventional or unconventional methods are failed for economic dispatch consideration. It gives better result for load sharing of units than other conventional methods. An artificial intelligence techniques based on Fuzzy Logic is also proposed for optimization of operating cost and power generation. It is reflected that numerical problems through fuzzy logic gives feasible and economical cost for power system operation. A set of linguistic fuzzy rules are developed to establish relationship between inputs and outputs for the development of fuzzy controller. The programming of all the algorithms has been implemented in MATLAB environment on Intel Atom Processor with 1.66 GHz frequency and 1 GB RAM. Fuzzy Logic Approach to solve such kind of problems has been studied in this work.

Keywords: Unit Commitment (UC); Economic Dispatch (ED), Lagrangian Multiplier (LM), Incremental cost (IC), Load Schedule (LS), Operating Cost (OC), Fuzzy Logic (FL), Lagrange Algorithm (LA), SR (Spinning Reserve).

1. INTRODUCTION

The size of Electrical Power System is increasing rapidly to meet the energy requirements. A number of power plants are connected in parallel to supply the load by inter-connection of power stations.With the developments of integrated power system(grid system),it becomes necessary to operate the plants most economically[1]."Economic Dispatch" has a common general meaning – the practice of operating a coordinated system so that low cost generators are used as much as to meet the possible demand, with more expensive generators are brought online when load demand increases. Power plants should be considered to supply load. Unit Commitment is not same as economic dispatching. Dispatching consists of fitting a given set of power plants into a certain electric demand whereas Unit commitment appoints the set of plants from which dispatching can choose.Unit commitment choose plants taking into account a wide variety of parameters, technological aspects (such as minimal operating point, minimum up and down time and transient behavior) as well as economical considerations (such as start- up cost and operational costs) and social elements (such as availability of staff and work- schemes).Unit commitment enables utilities to minimize electricity generation costs [6, 29].

Objective and Scope

LA and FL are extensively used in operation of Power System utilities. The economy of these algorithms will be more clear when the goal is to schedule the commited generators over load cycle to satisfy various parameters like load demand ,maintain voltages and frequency etc within prescribed tolerance and minimize operating cost without disturbing the other systems. An approach for solving unit commitment based on advanced programming method using LA and FL has been proposed. Lagrangian algorithm is based on equal incremental cost curve technique and widely used in different environments where other conventional or unconventional methods are failed. It gives better result for load sharing of units than other conventional methods. The simplicity and flexibility of this programming model is that it can extend upto n no. of units with incorporation of any n no. of constraints involved where other techniques are subjected to different restrictions. An artificial intelligence techniques based on Fuzzy Logic is also proposed for further optimization of operating cost and power generation. It is reflected that numerical problems through fuzzy logic gives feasible and economical cost for power system operation. A set of linguistic fuzzy control rules are developed to establish relationship between inputs and outputs for the development of fuzzy controller. The programming of all the algorithms has been implemented in MATLAB environment. Results indicating comparison of the cost solutions using the FL, LA have been presented in this work. Hybrid algorithms based on other soft computing techniques can be incorporated with more constraints for unit commitment optimization. More accuracy and fast computation time can be observed on 128 ,256 bit processors based on DSP,FPGA systems.

2. ECONOMIC DISPATCH

Economic dispatch is defined as the process of allocating generation levels to the generating units in the mix so that the system load is fully supplied in the most economic way. The method of economic dispatch for generating units at different loads must have total fuel cost at the minimum point. There are many conventional methods that are in use to solve economic dispatch problem such as Lagrange multiplier method, Lambda iteration method and Newton Rap son method. In the conventional methods, it is difficult to solve the optimal economic problem if the load is changed. It needs to compute the economic dispatch each time which uses a long time in each of computation loops .It is a computational process where the total required generation is distributed among the generation units in operation, by minimizing the selected cost criterion, and subjects it to load and operational constraints as well. Most programs use economic dispatch in real- time energy management power system control to allocate the total generation among the available units, unit commitment and in some other operation functions .

Optimal Generation Scheduling

The economic dispatch problem is defined as the one that minimizes the total operating cost of a power system while meeting the total load plus transmission losses within generator limits. When long distance transmission of power is involved, the transmission losses cannot be ignored. If the transmission losses are neglected, then the total system load can be optimally divided among the various generating plants using the equal incremental cost criterion. A modern electric utility is capable of serving a vast area of relatively low load density. The transmission losses may vary from 5 to 15 per cent of the total load. It is essential to keep an account for transmission losses while developing an economic load dispatch policy. Mathematically, the problem is defined as

Minimize $F(P_{gi})=\sum a_i P_{gi}^2+b_i P_{gi}+c_i$ Rs/hr where i=1 to NG………(2.2)

Subject to

1) The energy balance equation
$\sum P_{gi}=P_D+P_L$……………………………………………… (2.3)

2) Inequality Constraint
$P_{gimin} \leq P_{gi} \leq P_{gimax}$………………………………(2.4)

Where a_i,b_i,c_i are cost coefficients, P_D is the load demand, P_{gi} is the real power generation and act as decision variable, NG is no. of generator buses, P_L is the power transmission loss.[1]

B-coefficients are used to express transmission losses as a function of generator powers. Under normal operating conditions, the transmission losses are found to be quadratic in the injected bus real powers. The general form of the loss formulae using B-coefficients is

$P_L=\sum\sum P_{gi}B_{ij}P_{gj}$……………………………………………..….(2.5)

Where P_{gi} and P_{gj} are the real power injections at the ith and jth buses
B_{ij} are the loss coefficients which are constant under certain assumed condition
NG is the number of generation buses.

The constrained optimization problem can be converted into an unconstrained optimization problem by using Lagrange multiplier method. It is used where the function is minimized (or maximized), satisfying the side conditions in the form of equality constraints[1]. Using Lagrange multipliers, an augmented function is defined as

$L(P_{gi},£)=F(P_{gi})+ £(P_D+P_L- \sum P_{gi})$
Where £ is Lagrangian multiplier

The incremental cost can be obtained as : $(\Delta F(P_{gi})/ \Delta P_{gi})L_i=£$
Where $L_i=1/(1-\Delta P_L/ \Delta P_{gi})$
L_i is the penalty factor of ith plant

The value of P_{gi} can be obtained as
$P_{gi}=£(1-B_{i0}-\sum 2B_{ij}P_{gi})-b_i/2(a_i+£B_{ii})$

Without transmission losses
$P_{gi}=£-b_i/2a_i$

The incremental cost can be obtained as: $£=(P_D+\sum b_i/2a_i)/ \sum 1/2a_i$
Where i and j are 1 to NG(NG is no. of generators)

Benefits of Economic Dispatch

1. If the geographic scope and electrical diversity of the area taken under unified dispatch increases, then economic benefits also tend to increase.
2. Retail customers benefit if cost savings are passed through in retail rates.
3. Economic dispatch reduces fuel consumption and emissions as high-efficiency units frequently displace lower-efficiency units using the same or similar fuel. Economic dispatch requires well maintained balance between economic efficiency, reliability, and various other factors, such as the ability of a given generating unit to shift output at short notice, and scheduling limitations imposed by environmental laws, hydrological conditions, and fuel characteristics. It means that the economic dispatch is “constrained cost minimization process”

Current Practices for Optimizing Dispatch

1. Coal-fired generation resources are normally dispatched as simple options with the dispatch cost consisting of the fuel cost, environmental cost and variable operating and maintenance costs. In addition, many of these resources are occasionally used to supply operating reserves as well (contingency and regulating) for the control areas.
2. Natural-gas-fired generation is normally dispatched as a spark spread option without long-term fuel contracts and includes variable operating, maintenance, and start-up costs.The decision of natural gas and electricity purchase is made in the day-ahead market and again in the hour-ahead market.
3. Hydro generation resources, with storage capability, are normally dispatched as swing options based on the opportunity cost of dispatching in some other time period.
4. Contractual resources are dispatched either as simple, spark spread, wing, or compound options, depending on the terms of the agreements.

3. UNIT COMMITMENT

The unit commitment involves the selection of units that will supply the anticipated load of the system at minimum cost over a required period of time as well as provide a specified margin of the operating reserve, known as the spinning reserve. The on-line Economic dispatch distributes the load among those operating units that are paralleled with the system in such a manner so as to minimize the total cost of supplying the minute to minute requirements of the system.

3.1 Constraints in Unit Commitment

Many constraints can be applied on the unit commitment problem. Each individual power system, power pool, reliability council, et.al, may impose different rules on the scheduling of units, depending on the generation makeup, load-curve characteristics.

3.2 Fuel cost computation

Fuel cost in unit commitment problem may be divided into two categories: the transitional cost and production or generation cost. Generally the transitional cost is the cost associated with the starting of the unit and it may also include shut down cost. The production cost is the fuel cost required to meet the load. It depends on the unit loading heat rate and fuel price. Computation of these costs is given below:

3.3 Transitional Cost

The shutting down of units are not associated with cost, normally but a provision can be made to include shutdown costs in the computation of total cost. A constant cost may be specified for each unit as the shut down cost. This cost is taken to be independent of the length of time; the unit has been running before the shutdown. In the unit commitment problem usually some form of startup cost is considered. A simple practice is to assume a constant cost irrespective of the unit down time. However, in order to provide a more accurate measure of the actual cost involved, a time dependent start up cost is required. The startup cost is expected to be dependent on the temperature of the unit considered and hence on it's down time. Since the cooling rate of a unit is approximately exponential, an exponential start up cost curve is generally accepted though other forms of cost curve may also be used. It will be more economical to keep the unit in hot standby instead of shutting it down completely. The choice between shutdown and hot standby will depend on the two cost curves and the length of time, a unit is kept out-of-service. Generally, a constant fuel rate is required to maintain the boiler temperature and pressure, and thus the standby cost curve may be assumed to be a linear function of the shutdown time. As a result of this, a unit will be allowed to cool or be in hot standby as determined by the lower of the startup and hot standby costs.

3.4 Production cost

The production cost is the cost of the fuel required by a given set of on-line generating units to meet the load demand in the system. Since the overall objective of the unit commitment problem is to minimize the overall total cost, hence the production cost should also get minimized as well. Numerous methods of economic dispatch are available to determine the minimal production cost. As compared to the number of economic dispatches that would be performed, a simple, feasible and fast economic dispatch procedure is used. The transmission losses are assumed to be a quadratic function of the total system generation. The dispatching is carried out such that unit generations are always within their upper and lower limits. It is also taken care that the various spinning reserve requirements described above are not violated. A dispatch which satisfies all of the constraints is termed as a feasible one. Using the described method, an economic and feasible dispatch is always determined whenever one exists. Since each unit section is considered only once and no iteration is involved, the dispatch is fast. The units are considered once and in the order of pre specified priority in order to reduce the dispatching effort.

3.5 Unit Commitment Solution Methods

The unit commitment problem determines the combination of available generating units and schedules their respective outputs in order to satisfy the forecasted demand maintaining the minimum total production cost, under the operating constraints enforced on the system for a specified period that usually varies from 24 hrs to one week. Attempts to develop rigid unit operating schedules, for more than one week in advance are extremely curtailed due to uncertainty in hourly load forecasts at lead time. Apart from achieving minimum total production cost, generation schedules need to satisfy a number of operating constraints. These constraints reduce freedom in their choice of start up and shutting down generating units. The constraints to be satisfied are usually the status restriction of individual generating units, minimum up time, minimum down time, capacity limits, generation limits for the first and last hour, power balance constraint, spinning reserve constraint, hydro constraints, etc. The high dimensionality and combinatorial nature of unit commitment problem failure made for the development of any rigorous mathematical optimization method, which is capable of solving any real-size system problem as a whole. The available approaches for solving unit commitment problem can usually be classified into heuristic methods and mathematical programming methods. In addition the proposed mathematical programming approaches are dynamic programming and Lagrangian relaxation. These two approaches are most widely used to develop industry grade unit commitment programs. Their major advantage being the reasonable computation time required by them when compared to other approaches. The most talked about techniques for the solution of the unit commitment problem are:

- Priority-list schemes
- Dynamic programming (DP)
- Lagrange relation (LR)

3.6 Economic Dispatch Vs Unit Commitment

At this point, it will be good to emphasize the essential difference between the unit commitment and economic dispatch problem. The economic dispatch problem assumes that there are N units are already connected to the system. The purpose of economic dispatch problem is to find the optimum operating policy for these N units. On the other hand, the unit commitment problem is more complex. It can be assumed that only N units are available and forecasting of the "to be served" demand has to be done. The question that is asked in the unit commitment problem area is approximated as follows, "Given that there are a number of subsets of the complete set of N generating units that would satisfy the expected demand, which of these subsets should be used in order to provide the minimum operating cost". This unit commitment problem can be extended over some period of time, such as 24 hours a day or 168 hours a week. Hence the unit commitment problem is much more difficult to solve. The solution method involves the economic dispatch problem as a sub problem. That is, for each of the subsets of the total units that are to be tested, for any given set of them connected to the load, the particular subset should be operated in optimally and economically. This will help in finding the minimum operating costs for that subset, but it will not specify which of these subsets is in fact the one that will give minimum cost over a period of time.

4. FUZZY LOGIC

Fuzzy logic has rapidly become one of the most among the present technologies for developing sophisticated control systems. Fuzzy logic addresses applications perfectly as it resembles human decision making power. It has the ability to generate precise solutions from certain or approximate information. It fills an important gap in engineering design methods that was left vacant by purely mathematical approaches (e.g. linear control design), and purely logic-based approaches (e.g. expert systems) in system design. While other approaches require accurate equations to model real-world behaviors, fuzzy design can work well with the ambiguities of real-world human language and logic. It provides an intuitive method for describing systems in human terms and automates the conversion of those system specifications into effective models. The very first applications of fuzzy theory were primly industrial, such as process control for cement kilns. However, as the technology kept on developing, fuzzy logic was also used in more useful applications. In 1987, the first fuzzy logic-controlled subway was opened in Sendai in northern Japan. Here, fuzzy-logic controllers made subway journeys more comfortable with smooth braking and acceleration and all the driver just has to push the start button! Fuzzy logic was also put to work in elevators to reduce waiting time. Since then, the applications of Fuzzy Logic technology have virtually exploded, affecting all the day to day things.

4.1 What does FUZZY means?

Fuzzy logic is a superset of conventional (Boolean) logic that has been extended to handle the concept of partial true values between "completely true" and "completely false". As its name suggests, it is the logic underlying modes of reasoning which are approximate rather than exact. The importance of fuzzy logic is derived from the fact that most modes of human reasoning, common sense reasoning, are approximate in nature. The essential characteristics of fuzzy logic as founded by Zadeh Lotfi are as follows:

- In fuzzy logic, exact reasoning is viewed as a limiting case of approximate reasoning.
- In fuzzy logic, matter of degree plays an important role.
- Any logical system can be fuzzified.
- In fuzzy logic, knowledge is interpreted as a collection of elastic or, equivalently , fuzzy constraint on a collection of variables.
- Inference is viewed as a process of propagation of elastic constraints.

4.2 Fuzzy Sets

A paradigm is a set of rules and regulations which defines boundaries and helps in solving problems within these boundaries successfully. For example the use of transistors instead of vacuum tubes is a paradigm shift - likewise the development of Fuzzy Set Theory from conventional bivalent set theory is a paradigm shift. Bivalent Set Theory can be proved somewhat limiting while defining a 'humanistic' problem mathematically.

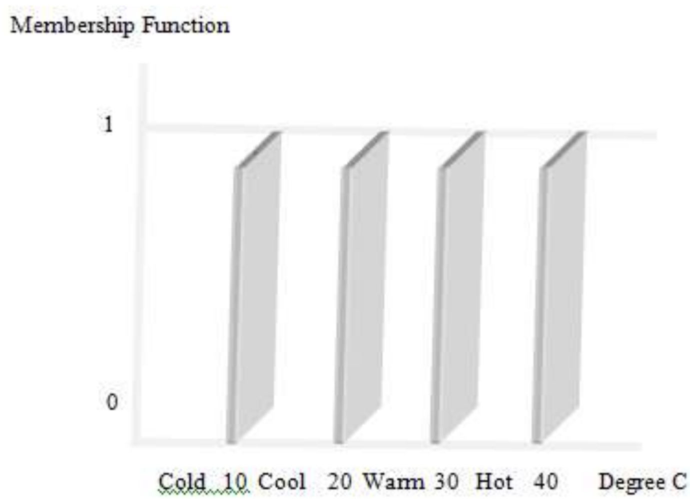

Fig 1: Bivalent sets to characterize the temperature of a room.

The most obvious limiting feature of bivalent sets that can be seen clearly from the diagram is that they are mutually exclusive - it is not possible to have membership of more than one set, for example opinion may vary as to whether 50 degrees Fahrenheit is 'cold' or 'cool'. Hence the expert knowledge we need to define our system is mathematically at odds with the humanistic world). Clearly, it is not accurate to define a transition from a quantity such as 'warm' to 'hot' by the application of one degree Fahrenheit of heat compared to this in the real world, a smooth (unnoticeable) drift from warm to hot would be visible. This natural phenomenon can be described more accurately by Fuzzy Set Theory.

Fuzzy Set theory involves the following Operations:

1) Union

2) Intersection

3) Complement

4) De Morgan's law

5) Associativity

6) Commutativity

7) Distributivity

4.3 Fuzzy Rules

Human beings make decisions based on rules. Although, we may not be aware of it, but whatever decisions are made are all based on computer like if-then statements. For example, if the weather is fine, then we may decide to go out. If the forecast says the weather will be bad today, but fine tomorrow, then we make a decision not to go today, and postpone it till tomorrow. Rules associate ideas and relate one event to another. Fuzzy machines, which always tend to mimic the behaviour of man, also work in the same way. However, the decision and the means of choosing that decision are replaced by fuzzy sets and the rules are replaced by fuzzy rules. Fuzzy rules also operate using a series of if-then statements. For instance, if X then A, if y then b, where A and B are all sets of X and Y. Fuzzy rules define fuzzy patches, which is the key idea in fuzzy logic[7] .

CONCLUSION

In this thesis, the comparison of optimized value of total cost obtained using conventional programming method Lagrange algorithm and soft computing technique fuzzy logic is implemented. An effective robust solution for unit commitment problem is necessary for optimium load sharing among units to carry out the economic dispatch. Unit commitment problem is complex where ambiguity exists due to no. of constraints and such problem can be addressed easily by using fuzzy logic. As the size of units increased and complicated constraints are imposed, it is difficult to address the problem using conventional methods. Fuzzy logic is used to solve this problem as outcome of logical representation of rules are easy to understand and it can apply to n no. of units. After evaluation, it is observed that total cost obtained is less in case of fuzzy logic as compared to LA .Fuzzy logic is more fast as compared to conventional programming methods. Hence, fuzzy based approach is more optimized as compared to traditional methods to solve unit commitment problem.

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