International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 9, September-2014, pp: (275-280), Impact Factor: 1.252, Available online at: www.erpublications.com

Economic Dispatch & its various impacts on Power System Generation

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Abstract: Economic dispatch is the short-term determination of the optimal output of a number of electricity generation facilities, to meet the system load, at the lowest possible cost, subject to transmission and operational constraints. The Economic Dispatch Problem is solved by specialized computer software which should honor the operational and system constraints of the available resources and corresponding transmission capabilities. It may also be defined as "the operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities"[1]

The main idea is that in order to serve load at minimum total cost, the set of generators with the lowest marginal costs must be used first, with the marginal cost of the final generator needed to meet load setting the system marginal cost. This is the cost of delivering one additional MW of energy onto the system. The historic methodology for economic dispatch was developed to manage fossil fuel burning power plants, relying on calculations involving the input/output characteristics of power stations. The author has tried to discuss its various impacts in power system generation.

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1. Introduction

Economic dispatch, by definition is an on-line function, carried out after every 15-30 minutes or on request in Power Control Centers. It is defined as the process of 2 calculating the power generation of the generating units in the system in such a way that the total system demand is supplied most economically.

The economic dispatch problem can be thought of as maximising the economic welfare W of a power network whilst meeting system constraints. For a network with n buses (nodes), where Ik represents the net power injection at bus k, and Ck (Ik) is the cost function of producing power at bus k, the unconstrained problem is formulated as:

$$\min_{I_k} (-W) = \min_{I_k} \left\{ \sum_{k=1}^{n} C_k(I_k) \right\}$$

Constraints imposed on the are the need to maintain a power balance, and that the flow on any line must not exceed its capacity. For the power balance, the sum of the net injections at all buses must be equal to the power losses in the branches of the network:

$$\sum_{k=1}^{n} I_k = L(I_1, I_2, \ldots, I_{n-1})$$

The power losses *L* depend on the flows in the branches and thus on the net injections as shown in the above equation. However it cannot depend on the injections on all the buses as this would give an over-determined system. Thus one bus is chosen as the Slack bus and is omitted from the variables of the function *L*. The choice of Slack bus is entirely arbitrary, here bus *n* is chosen.

Ensuring the best use of available resources is much more than a mechanical process of minimizing the total variable cost of electricity production. In seeking lowest-cost production, economic dispatch practices must take into account several factors, including: the continuous variation in loads and generators' inability to respond instantaneously; the need to maintain reserves and plan for contingencies in order to maintain reliability; and the scheduling requirements imposed by environmental laws, hydrological conditions, and fuel limitations. The nature of utilities has changed as some areas of the country have structurally unbundled and reorganized aspects of their generation and transmission systems. Utility generators have been supplemented by NUGs, built without a guaranteed franchise of customers to buy their output. In 2003, NUGs (including generation that was once utility owned but sold to independent power producers as well as generation owned by unregulated utility affiliates) accounted for 38 percent of total U.S. generation capacity and 27% of actual electricity production (Energy Information Administration, December 2004).

Oversight of utilities' performance in achieving affordable and reliable electricity has been a primary responsibility of state and federal regulatory agencies as well as local authorities and boards, depending on the form of ownership and organization of each utility. Thus, regulatory and ownership policies have an important effect on how economic dispatch is practiced by each utility or other dispatching entity. These policies affect whether the utilities that manage transmission systems own generation, the degree to which utility-owned generation competes with non-utility generation, and whether regional transmission organizations and independent system operators have been developed to manage the transmission system and generation dispatch across a wide geographic area less-efficient generation. As the geographic and electrical scope integrated under unified economic dispatch increases, additional cost savings result from pooled operating reserves, which allow an area to meet loads reliably using less total generation capacity than would be needed otherwise. Economic dispatch requires operators to pay close attention to system conditions and to maintain secure grid operation, thus increasing operational reliability without increasing costs. Economic dispatch methods are also flexible enough to incorporate policy goals such as promoting fuel diversity or respecting demand as well as supply resources. Over the long term, economic dispatch can encourage new investment in generation as well as in transmission expansion and upgrades that enhance both reliability and cost savings.

2. Literature Review

Gwo-Ching Liao and Ta-Peng Tsao (2002) presented a new approach, 'the hybrid genetic algorithm/fuzzy system and Tabu Search for short-term thermal generating unit commitment. He discussed four improvement plans for the GA. The four improvements include: a). The improvement about regulate scale of fitness function, b). The improvement in the selection items and reproduction strategy, c). The crossover ratio and mutation ratio are from the fixed value change to be determined using fuzzy system method, d). Importing the best local search method into the algorithm [1].

Li Maojun and Tong Tiaosheng [3] proposed a Gene Complementary Genetic Algorithm for Unit Commitment and constructed three kinds of genetic operators. The results of experiment show that the algorithm proposed in this paper is available for the UCP.

Ouyang and S. M. Shahidehpour [4] proposed the DP-TC algorithm and employed various heuristic strategies in the paper. Finally, experimental results are presented which support the methodology by utilizing a much smaller execution time while preserving the quality of the optimization.

One of the algorithm proposed in [1], known as DP-SC, uses a strict priority list search sequence to reduce the possible combinations at every stage. Another method by the same authors employs a fixed search window to truncate the priority list, in which only the truncated combinations are evaluated. This method, known as DP-TC, performs much better than DP-SC as an optimizer; however it requires a much longer processing time.

S. Jalilzadeh and Y. Pirhayati presented (2009) an Improved Genetic Algorithm (IGA) for UCP with lowest cost. A modified approach to the solution of unit commitment problem using genetic algorithms is proposed in this paper. Improvement in cost and quality of solution is obtained [3].

In order to obtain a near optimal solution in low computational time and storage requirements, with respect to all specified constraints, Alma Ademovic et al.(2010) presented a Genetic Algorithm using real-coded chromosomes in opposite to the more commonly used binary coded scheme[1].
D. Simopoulos and G. Contaxis (2004) proposed some new rules concerning the cooling schedule and the random generation of the initial solution of the system. The results obtained in system studies show the effectiveness of the proposed model and indicate the need for further work in this area [2].

Dhillon et al. formulated the multiobjective thermal power dispatch using non commensurable objectives such as operating costs and minimal emission. The epsilon-constraint method was used to generate non-inferior solutions to the multiobjective problem considering the operating cost as the objective and replacing emission objective as a constraint. More recently, multi-objective evolutionary algorithms have been applied to the problem at hand. Abido has pioneered this research by applying NSGA , NPGA and SPEA to the standard IEEE 30-bus system. In fact, it has been shown that NSGA-II can obtain minimum cost and minimum emission solutions comparable to Tabu search . Not long after the introduction of the environmental consideration in the economic dispatch problem, researchers started considering stochastic approaches bearing in mind the uncertainties that are inherent in real-world situations. Viviani and Heydt incorporated the effects of uncertain system parameters into optimal power dispatch. Their method employed the multivariate Gram-Charlier series as means of modeling the probability density function (p.d.f.) which characterizes the uncertain parameters. Parti et al.

Extended the Lagrange multiplier solution method to solve the economic thermal power dispatch problem using an objective function consisting of the sum of the expected production costs and expected cost of deviations (a penalty term proportional to the expectation of the square of the unsatisfied load because of possible variance of the generator active power). Bunn and Paschentis developed a stochastic model for the economic dispatch of the electric power. These authors used a form of stochastic linear programming method for online scheduling of power generation at 5 minute intervals taking into account the mismatch between dispatched generation and actual load demanded. Experimental results on real data demonstrated the efficiency of the approach compared to conventional deterministic linear programming model. Dhillon et al. [2] have used the weighted minimax technique to obtain trade-off relation between the conflicting objectives and fuzzy set theory is subsequently used to help the operator choose an optimal operating point.

One of the first attempts to combine the UC problem and the economic dispatch problem is made by Birge and Takriti. In their work they handle the stochasticity of load by using multi-stage stochastic programming techniques. They approximate the nonlinear subproblems to their linear equivalents and solve these to attain a lower bound on the solution. Then they employ heuristic rules to derive a feasible solution. To combine these two different time horizon problems, they utilize match-up scheduling.

3. Input Output Curve of Generating Unit

Power plants consisting of several generating units are constructed investing huge amount of money. Fuel cost, staff salary, interest and depreciation charges and maintenance cost are some of the components of operating cost. Fuel cost is the major portion of operating cost and it can be controlled. Therefore, we shall consider the fuel cost alone for further consideration. To get different output power, we need to vary the fuel input. Fuel input can be measured in Tonnes / hour or Millions of Btu / hour. Knowing the cost of the fuel, in terms of Rs. / Tonne or Rs. / Millions of Btu, input to the generating unit can be expressed as Rs / hour. Let Ci Rs / h be the input cost to generate a power of Pi MW in unit i. Fig.1 shows a typical input –output curve of a generating unit. For each generating unit there shall be a minimum and a maximum power generated as Pi_{min} and Pi_{max}.

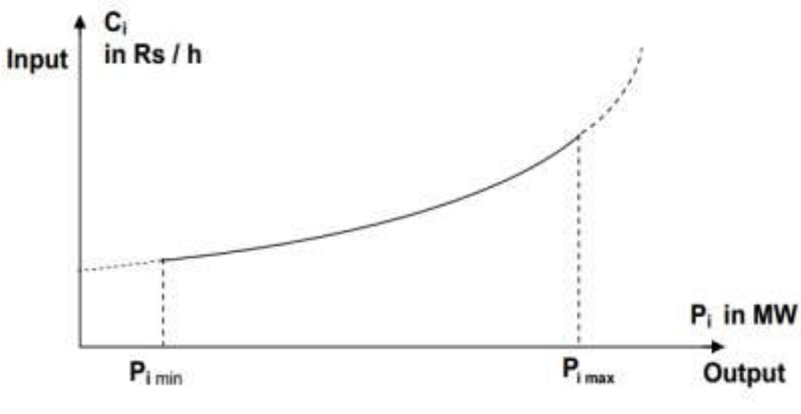

Fig.1: Input-Output curve of a generating unit

If the input-output curve of unit i is quadratic, we can write A power plant may have several generator units. If the input-output characteristic of different generator units are identical, then the generating units can be equally loaded. But generating units will generally have different input-output characteristic. This means that, for particular input cost, the generator power Pi will be different for different generating units in a plant.

Based on the on-line/off-line schedule of generating units determined by unit commitment, economic dispatch (ED) uses the incremental cost curves of on-line generating units, which are the slope (the derivative) of their cost curves with respect to power output, to calculate for their most economical generation output level. Once the dispatch levels of on-line units are determined, their fuel cost curves and O&M cost curves are used to calculate for the total fuel cost and the total O&M cost [6].

4. Economic Dispatch

For much of the past century, vertically integrated utilities conducted economic dispatch within their individual control areas, meaning that each utility coordinated the operation of its own generators to deliver electricity efficiently across its own transmission lines to serve its own customers. The utility's dispatchers knew the capabilities and costs of the firm's resources and the strengths and weaknesses of its transmission system. Sometimes they purchased energy from outside the firm's own system and deliberately shipped ("wheeled") electricity across other utilities' transmission lines. Those practices began to change several decades ago with the growth in inter-regional bulk energy sales (as with hydropower sales from Quebec into New York and seasonal exchanges between California and the Pacific Northwest) and the proliferation of "qualifying facilities" (QFs) under the Public Utilities Regulatory Policy Act of 1978. QFs' energy production had to be integrated in real time with a utility's own power production and transmission flows. It also became apparent that significant economies could be achieved if several utilities within a region operated their plants in a single power pool for integrated dispatch; pooling took place primarily in the northeastern U.S. with the formation of the Pennsylvania-New Jersey-Maryland, New England, and New York power pools. Because each of these areas had a highly networked transmission system, the member utilities could reduce the both energy and capacity costs for their customers through pooled dispatch and reserve-sharing [5].

What is Economic Dispatch?

"Economic dispatch" has a common, general meaning – the practice of operating a coordinated system so that the lowest-cost generators are used as much as possible to meet demand, with more expensive generators brought into production as loads increase (and conversely, more expensive generation eliminated from production as load falls). Most people agree with EPAct's definition of economic dispatch – "the operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities" – but the details of how this definition is put into practice can vary significantly. Electricity loads vary over time, rising and falling in daily and weekly patterns. Because electricity travels at the speed of light and cannot be stored inexpensively, generation must be available that can follow changes in load almost instantaneously. However, generators vary widely in their costs and capabilities; fossil-fired units with low marginal costs tend to be relatively inflexible, and generators that can follow load tend to be more expensive. Generators are also subject to fuel limitations and environmental regulations that restrict their availability. Finally, reliability considerations demand that excess 10 generation be available in reserve, along with transmission capacity, to respond to sudden, unplanned contingencies. These characteristics of the power system lead to a natural sequencing in system operations -- first, determine which units should be turned on and made available to serve loads (called unit commitment), and, second, determine how much production to call from each resource (economic dispatch). To better define the terms:

Economic dispatch is the economic optimization process that determines a combination of generators and levels of electricity output to meet demand2 at the lowest cost, given the operational constraints of the generation fleet and the transmission system [7].

Security-constrained3 economic dispatch (SCED) is an economic optimization process that searches for the set of resources and production levels available at a specific point in real time that minimizes the cost of electricity production, subject to a variety of operational constraints to assure reliable grid operations. Adequate reliability practices comply with the reliability practices and standards of NERC, or those that will be adopted by FERC under the recently enacted EPAct. Organizations that practice SCED check system conditions and re-optimize dispatch instructions frequently (usually every five minutes). Economic dispatch uses the resources available on the system for the time frame under analysis.

Security-constrained unit commitment (SCUC) searches for a least-cost reliability solution by identifying the appropriate mix of units (capacity) to meet projected loads. SCUC is an optimization process that is typically run one day ahead of actual dispatch. This process looks at expected demands, resource availability, and system conditions and finds the combination of resources that should be committed to operate the next day to produce the least-cost mix of energy and reserves subject to expected operational considerations (such as start-up costs and times, minimum run levels, and ramp rates) and grid constraints. Entities that practice SCUC perform the analysis one or more times during the day preceding the dispatch day and issue commitment orders around 5 or 6 p.m. for the units needed the next day. Dispatchers who perform SCUC then conduct SCED for daily operations, but not every dispatching entity that performs SCED first conducts SCUC.

As indicated above, economic dispatch works to manage resources across time. Different resources have differing production capabilities and characteristics. A generator's production level this afternoon will be affected by its on-line status and production levels this morning and yesterday (e.g., a baseload coal plant or a hydroelectric pumped storage plant) as well as whether maintenance was performed on it last quarter or last year (e.g., nuclear refueling or a loadfollowing plant that undergoes maintenance in non-peak months). This means that although the primary focus of economic dispatch is daily and minute-to-minute operations, the process must look beyond a single day to optimize the operation and cost of resources across a season [8].

5. The Benefits of Economic Dispatch & its Impact

This section looks at the "potential benefits to residential, commercial, and industrial electricity consumers nationally and in each state if economic dispatch procedures were revised to improve the ability of NUGs to offer their output for inclusion in economic dispatch," as directed in EPAct Section 1234. The assessment is based on a review of recently published studies and responses to the Department's brief questionnaire. The limited time available for this study did not allow the Department to perform new modeling and quantitative analysis specifically of economic dispatch impacts. It is important to bear in mind that most of the materials used for this assessment are not focused solely or even directly on the question of economic dispatch as posed by the Act. This review is not intended to evaluate the methods and assumptions of the studies examined, so the Department's findings are bounded by the studies' methods and assumptions. This review does, however, point out issues that merit attention in future studies.

The actual economic dispatch problem is non-convex in nature due valve point effect, multiple fuels and prohibited operating zones. Dynamic programming has been used to solve this problem, but due to curse of dimensionality it has limitations. Thus for the accurate dispatch, the approaches independent of restrictions such as continuity, differentiability, convexity are potential solution methodologies.

Congressional Intent and Study Definitions

In assessing the benefits of economic dispatch, the term "benefits" is interpreted narrowly, as defined in EPAct Section 1234, by equating benefits with the direct, net economic savings that result from decreases in the price or cost of electricity to residential, commercial, and industrial customers (both nationally and in each state). Important but less direct or hard-to-measure impacts, e.g., on reliability or the environment, are not included. The studies estimate benefits from increased lower-cost generation and presume that those savings are passed through in retail rates to end-use customers (even though that is not always the case). When it is available, information on the economic costs associated with securing increased dispatch benefits (e.g., the cost of establishing and running an RTO) is noted because the benefits to electricity consumers would be net of these costs.

It is not possible to estimate the benefits of economic dispatch to different customer classes and states based solely on the studies of economic dispatch to date, because few of these studies disaggregated benefits to the level of individual customer classes or individual states. The lack of information reflects the aggregated nature of the regions studied. Equally important, assessing the impacts of dispatch changes on retail customers would require consideration of federal and state ratemaking policies, such as allocation of FTRs and the effects of retail rate freezes. The studies reviewed do not treat these issues consistently [8].

It is not always clear how the different studies classify non-utility generation. Every study appears to use a common meaning for "utility-owned generation" -- that which has 32 been placed in the rate base for capital-cost recovery within the service area of the dispatching party. However, an off-system (export) sale from one utility-owned power plant into another utility's service area would be considered non-utility generation in the latter's economic dispatch stack. In regions where dispatch is performed by vertically integrated -- yet functionally unbundled -- utilities, this study uses the term "non-utility generator" to include any generation not owned by the party conducting the dispatch; other studies may use NUG to mean merchant generators or IPPs. This lack of consistent definition and focus makes it impossible to tally the impacts of economic dispatch upon NUGs.

Conclusions

In this paper, the author has discussed the Economic Dispatch Problem and its various impacts on power system generation. Power Economic Dispatch (ED) is necessary and vital step in power system operational planning. It is nonconvex constrained optimization problem defined as the process of calculating the generation of the generating units for the minimum total production cost in such a way that both equality and inequality constraints are satisfied. In system operation studies generators are represented by input-output curves. In the first case, the stochastic solutions obtained are dominated by the deterministic ones except for the two extreme solutions. This means that in practice, real-world operation cost and emission would be always higher except if the power system is operated at either its minimum fuel cost (economic dispatch) or minimum emission (environmental dispatch). In the second case, the minimum emission solution is not affected by stochastic considerations but all other solutions have higher cost for the same emission level. The minimum cost solution being higher than the deterministic one by about 6 $/hr. The reliability measure used in this study confirms the non-dependence of the emission level from comparison of operating points based on different pseudo-weights of the two objectives. Thus, in real-world situations, the power system would be operated at an operating point, which would have higher fuel cost and higher emission level than the calculated and planned operating point. In other words, the real-world (stochastic) operating point would always be dominated by the deterministic one.

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