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Modeling Additional Operational Costs Incurred Due to Absent of the Optimal Correction in Electrical Systems

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Abstract: This study presents a model of the additional embedded operational costs incurred due to the absence of the optimal correction in the electrical systems. The first contribution of this study is the definition of a general model that combines into several important models. Next, it formulates a nonlinear algorithm that relaxes the optimal schedule and serves as a lower bound on the cost of an optimal mode this study also presents an efficient algorithm for finding a solution (approximated) to the nonlinear program. Also it emphasizes the importance of the power operation management as decision makers for the electric power system in the industrial sector where the dispatch operator can avoid the additional embedded operating costs by continuous correction to follow the optimality. The relationship between the additional costs and the absent of the optimal corrections as a function was demonstrated.

Key words: Power losses, additional costs, mathematical model, optimal corrections, cost function

INTRODUCTION

While the daily growth and increasing of world energy resources prices and less improvement has been achieved in the financial aspects for the electrical companies. The necessity leads to create and find out new methods to improve and minimize the costs of the electrical energy.

Obviously the optimal running mode is an integration of: management, control, monitoring, maintenance and the electric power is at the minimum cost of electrical energy (producing and distributing to the customers).

The cost-minimizing choice of inputs depended on two essential sets of parameters: the given output level and the given factor prices. It is obvious that if we changed relative factor prices, the cost-minimizing choice of inputs would change. The cost function and its analysis is due largely to the famous research of Samuelson (1983) and Shephard (2006).

The analysis of the cost function in the electrical power industries can be achieved with global analyzing of the electrical systems components and modes.

Generally, the Optimal operation mode of the power electrical system is defined, with regard to voltage and current behavior, an ideal optimal situation that in practice can be only approximately achieved (Glavitsch and Bacher, 1991).

The most important reasons of deviation from the ideal optimal mode can be summarized as follows (Abdullah, 2005):

- Network configuration variations, in proximity to loads: for example, frequent inserting and disconnecting operations of loads, or opening and closing operations of distribution networks due to local requirements or operation of protection systems (e.g., with stormy weather)
- Load variations: for example, those caused by intermittent operating cycles (traction systems, rolling mills, tooling machines, excavators, welding machines, etc.)
- The physical dissymmetries of the electrical part of the system: for example, in lines, transformers and mostly in loads (as single-phase loads), which can be amplified by anomalous connections (e.g., the disconnection of a phase or an unsymmetrical short-circuit)
- The nonlinearities of the electrical part, with reference to the instantaneous values of voltages, currents, magnetic fluxes, etc.: for example, saturations and magnetic hystereses and granular effects due to winding distribution and slots in the machines; electrical characteristics of arc furnaces, fluorescent lights, thyristor controlled converters, static compensators, etc.
- Finally, the interconnections between very large systems (e.g., neighboring countries)

Regarding the above-mentioned hypotheses the operator at the dispatch control has to improve this situation as a responsible decision maker by keeping the

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system on the optimal operating condition within minimum and convenient operating costs (Miller, 2002). The dispatching task activity has to take the system to the optimality as far as the decision is right (Valenzuela *et al*., 2000). The dispatching task involves continuous monitoring and interaction with archived and real-time data using a typical number of dispatch means (Niimura and Ko, 2002).

ELECTRICAL POWER SYSTEM COSTS

Losses of the electrical power system have a considerable effect on the active power generation cost and allocate them fairly among the power system agents is essential to economic efficiency of the electric energy market. As the operational cost model evolves over time, any impact or change to the operation can be easily incorporated into the model with effects to the operation accurately forecasted.

Operational cost modeling of the electrical systems is not a one-time event, but rather an iterative process that continues to be refined over time until you have a finely tuned model of your operation. It depends mainly on the load flow problem which is specifying the loads in megawatts and megavars to be supplied at certain nodes or busbars of a transmission system. The model of the transmission system is given in complex quantities since an alternating current system is assumed to generate and supply the power and loads (Dimitrovski and Tomsovic, 2005).

Any change to the operation can then be applied to the model and the impact on cost, time, main power requirements and service levels can be accurately predicted. The costs generally are known as an average cost and its marginal cost.

The general cost function for the electrical power station according to Sadat (2002), is given by the equation:

$$C = \int_0^T \sum_{j=1}^{m} C_j P_{Gj} dt \rightarrow \min \tag{1}$$

Or

$$C = \int_0^T \sum_{j=1}^{m} B_j . C_u P_{Gj} dt \rightarrow \min \tag{2}$$

Where:

P_{gj} = The active generated power
C_j = The fuel costs to generate
P_{gj} in j = Power station
B_j = The fuel consuming in j station
C_u = Cost of fuel per unit, m- Stations number

The $C_j = B_j.C_u$ is a nonlinear function for the active power P_{gj}. When transmission distances are very small and density is very high, transmission losses are neglected and the optimal dispatch of generation is achieved with all plants operating at equal incremental production cost (Chen *et al*., 1995).

In large interconnected network where power is transmitted over long distances, transmission losses are a major factor and affect the optimum dispatch of generation. One common practice for including the effect of transmission losses is to express the total transmission losses as a quadratic function of the generator power outputs P_L.

$$P_L = \sum_{i=1}^{n_g} \sum_{j=1}^{n_g} P_i B_{ij} P_j \tag{3}$$

Or the more general well known formula containing a linear term and a constant term (Korn's loss formula (Sadat, 2002)) as:

$$P_L = \sum_{i=1}^{n_g} \sum_{j=1}^{n_g} P_i B_{ij} P_j + \sum_{i=1}^{n_g} B_{0i} P_i + B_{00} \tag{4}$$

The coefficients B_{ij} are called losses coefficients and they are assumed constants and reasonable accuracy can be expected provided the actual operating conditions are close to the base case where, the B-constants were computed. There are various ways to obtain these B-constants.

The optimal economic dispatching problem is to minimize the overall generating costs C_{Total} (Eq. 1) as a function of plant output, subjected to the constraints that generation should equal total demands and losses.

$$P_i = P_D + P_L \tag{5}$$

The network equations can be formulated in systematically in a variety of forms. The resulting equations known as the power flow equations and mostly solved by iterative techniques.

Power flow studies, commonly referred as load flow, are the backbone of power system analysis and design. It is also required for planning, operation, economic scheduling and exchange of power utilities, transient stability analysis and contingency studies. The optimal dispatch can be estimated and found out using the Lagrange multiplier mainly.

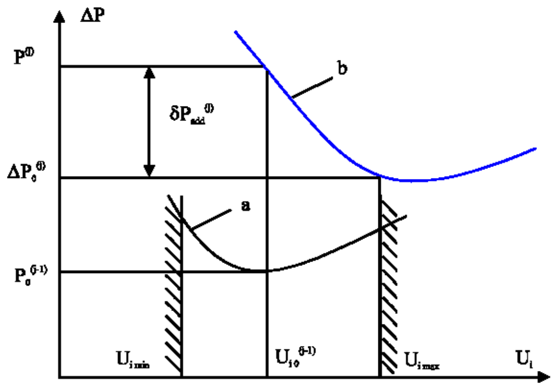

Fig. 1: The dependence of the active power losses on the parameters of the control devices (curve a for the j-1 mode, curve b -for j mode

THE INFLUENCE OF THE CONTROL DEVICES ON THE ELECTRICAL POWER SYSTEM LOSSES

The influence of the control devices on the electrical power system losses is a postulate logic issue. To describe this situation, Fig. 1 shows an example of the relationship between the active power losses ΔP on the parameters of the control devices (CD) Ui in a power system. The curve a for the j-1 load mode and curve b for j load mode. The first mode optimal parameters of control devices are fulfill with $U_{i\,0}^{(j-1)}$ and active power losses $\Delta P_0^{(j-1)}$.

During normal Load variations (demand), the current and the power flow also changed and there is a great need to keep the regime in the optimal minimum operating power losses zone which theoretically corresponds with the minimum costs. This can be achieved be the means of different control devices during operation in the system such as: Tap-changing transformers and controlled compensators.

To get to $\Delta P_0^{(j)}$ position, passing throw (j-1) Load variations, the parameters of the controlling devices should be adjusted from $U_{i\,0}^{(j-1)}$ to $U_{i\,0}^{(j)}$. The active power losses may differ from $\Delta P_0^{(j)}$ to $\Delta P^{(j)}$. If the correction is absent, this will lead to additional active power losses (which could be avoided by continuous corrections and regulations):

$$\delta P_{add}^{(j)} = \Delta P^{(j)} - \Delta P_0^{(j)} \tag{6}$$

The value of these additional losses depends and coincides with the rate between the running operating mode and the optimal mode. In general, these additional losses can be written as function:

$$\delta P_{add\,i} = f(U_i) \tag{7}$$

where, U- the operating function of the control devices and its correction or regulating margin,
i- corresponding the correction step.

Nevertheless, the equilibrium operation previously defined corresponds to, with regard to voltage and current behavior, an ideal situation which in practice can be only approximately achieved. Regarding the above-mentioned hypotheses (and assuming that stability holds), the most important reasons for deviation from the ideal behavior are:

ADDITIONAL OPERATIONAL COSTS

The additional Operational costs for a group of the electrical system:

$$C_{add} = \int_0^T \sum_{i=1}^m C_{add\,i} \tag{8}$$

where, $C_{add\ i}$ is the additional costs incurred due to the absent correction in the electrical systems modes. These costs are expressed in terms of active power losses. The C_{addi} depends on the additional active power losses, the time period and the power losses costs. Equation 20 can be performed as:

$$C^{(1)}{}_{add}i = \delta P_{add\,i}^{(1)} T_i b_0 \tag{9}$$

where, $\delta P_{add\,i}^{(1)}$ the additional active power losses costs incurred due to absent correction in the electrical power system at the first stage for the ith part of the power system or substation.

T_1 = Time period of the first stage for the i[th] part of the power system
b_0 = Losses costs in kW per hour

Obviously there is a clear logical relation between additional Operational costs C_{add} and the number of steps regulating of switch gears N_{sg} for the correction operation of the power system. This relation can be reflected in mathematical forms by means of statistical analysis.

The regression function classic statistical problem is to try to determine the relationship between two random variables X and Y. Linear regression attempts to explain this relationship with a straight line fit to the data. The linear regression model postulates that (Draper and Smith, 1998).

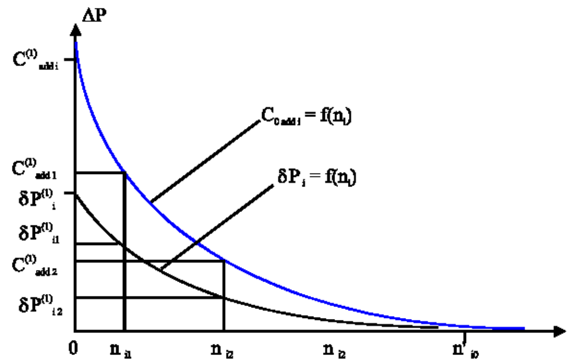

Fig. 2: The relation between the additional costs $C_{add\,i}$ and the active power losses δP_i

$$Y = a + bX + e \tag{10}$$

where, the residual e is a random variable with mean zero. The coefficients a and b are determined by the condition that the sum of the square residuals is as small as possible.

The regression analysis for curve fitting defined on the basis of the graphical practical results.

The relation $\delta P_{add\,i} = f(U_i)$ can be expounding as the additional losses and the switchgear numbers for the equipment of the electrical system in Fig. 2 1st curve. And the n'_{i0} value recognize for every ith equipment by:

$$n'_{0i} = \left| \frac{U_{i0}^{(l-1)} - U_{i0}^{(l)}}{U_{step\,i}} \right| \tag{11}$$

where, $U_{step\,i}$ regulation step of transformation ratio for the i^{th} transformer (for example). The time period T_1 for ℓth step characterized by the 24 h load graph (load demand) and does not depend on the number of switchgears. The b_0 losses costs in kW per hour directly depend on the configuration topology of the electrical network. Consequently, the interdependency of the additional costs $C_{add\,i}$ on the switchgear numbers can be reflected by taking corresponding coordination's of δP_i and the relation $\delta P_i = f(n_i)$ (Fig. 2).

The $C_{add\,i} = f(n_i)$ pattern will be as it shown in Fig. 2 curve 2. For any configuration of the electrical network system, the curves can be contrived by the experimental results of the load flow calculations and analysis. When the model function is not linear in the parameters the sum of squares must be minimized by an iterative procedure. This introduces many complications which are summarized in the differences between linear and non-linear least squares. Regression models predict a value of the y variable given by known values of the x variables. If the prediction is to be done within the range of values of the x variables where they are used to construct the model is known as interpolation (Kotsiantis *et al*., 2006).

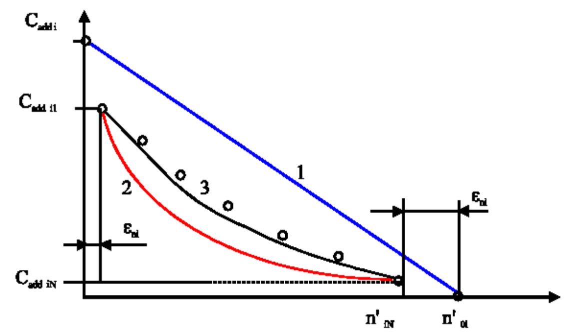

Fig. 3: The general type regression function which fulfill with the $C_{add\,i} = f(n_i)$ approximation

Table 1: Regression functions and its standard deviations

The regression function	The deviations $\lvert\hat{C}_{add\,i} - C_{add\,i}\rvert$*100%
$\hat{C}_{add\,i} = a_i n_i + b_i$	≤10
$\hat{C}_{addi} = \dfrac{1}{a_i n_i + b_i}$	≤20
$\hat{C}_{addi} = A_i n_i^{\alpha_i}$	≤5

Once a regression model has been constructed, it is important to confirm the goodness of fit of the model and the statistical significance of the estimated parameters. A number of N experimental steps on the curve $C_{add\,i} = f(n_i)$ in Fig. 3, can show the with different steps. In Table 1 a different types of the regression function are shown. The general form is $C_{add\,i} = \psi(n_i)$, where, $C_{add\,i}$ is regression function weight distances between the variables of $C_{add\,i}$ and n.

The standard deviations for $|\hat{C}_{add\,i}\text{-}C_{add\,i}|$ are used, together with the assumption that the errors belong to a normal distribution, to determine confidence limits for the parameters. The choice of the regression function can be perspicuous by using the flowing steps:

Using the input data as a result of the N experiments for the electrical system to find the approximation coefficients for the regression function $\hat{C}_{add\,i} = \psi(n_i)$. For which the deviation $|\hat{C}_{add\,i}\text{-}C_{add\,i}|$ used for the same points.

The experimental relation (function) of the running and maintenances costs on the switchgear numbers with acceptable accuracy can be $\hat{C}_{addi} = A_i n_i^{\alpha_i}$ with the condition $A_i>0$, $n_i> 0$, $a_i<0$.

THE REGRESSION MODEL COEFFICIENTS

The regression coefficients, representing the amount of the dependent variable $\hat{C}_{addi}$ changes when the corresponding independent changes 1 unit (step) for ith part of the electrical power system, which have the form:

$$\hat{C}_{addi} = A_i n_i^{\alpha_i} \tag{12}$$

Using the weighted least squares regression. The equation is a nonlinear by the time dependence, so using the least squares regression partially is not recommended. This function $\hat{C}_{addi} = A_i n_i^{\alpha_i}$ should be linearized by the natural logarithms (Kotsiantis *et al*., 2006). Logarithmic regression model equation generally can be presented as:

$$\ln \hat{C}_{addi} = \ln A_i + \alpha_i \ln n_i \tag{13}$$

This can be transformed as:

$$\ln \hat{C}_{addi} = Z_i, \ln A_i = D_i, \ln n_i = X_i$$

And the Eq. 12 will be:

$$Z_i = D_i + a_i X_i \tag{14}$$

In this case the least squares regression can be represented as:

$$\begin{cases} N D_i + a_i \sum_{j=1}^{N} X_{ij} = \sum_{j=1}^{N} Z_{ij} \\ \sum_{j=1}^{N} X_{ij} D_i + a_i \sum_{j=1}^{N} X^2{}_{ij} = \sum_{j=1}^{N} X_{ij} Z_{ij} \end{cases} \tag{15}$$

where, N- is the experiment number from which the X and Z are defined.

The last system can be retransformed as:

$$\begin{cases} N \ln A_i + a_i \sum_{j=1}^{N} \ln n_{ij} = \sum_{j=1}^{N} \ln C_{addij} \\ \sum_{j=1}^{N} \ln n_{ij} \ln A_i + a_i \sum_{j=1}^{N} \ln n_{ij}{}^2 = \sum_{j=1}^{N} \ln n_{ij} \ln C_{addij} \end{cases} \tag{16}$$

Solving these system Eq. 15 can be with boundary conditions as in Fig. 3:

$$n_{ij} = \varepsilon_{ni};\ C_{addi1} = f(n_{i1});\ n_{iN} = n'_{i0} - \varepsilon_{ni};\ C_{addiN} = f(n_{iN})$$

where, ε_{ni} is the given accuracy for the switch gear numbers n_i considering it is discrete.

The regression coefficients from Eq. 16 for approximation properties of Eq. 12 for ith part of the electrical power system are weighted. The weights estimate the relative predictive power of each independent, controlling for all other independent variables in the equation for a given model. The standardized version of the coefficients is the weights and the ratio of the coefficients is the ratio of the relative predictive power of the independent variables. Associated with multiple regression, multiple correlation, which is the percent of variance in the dependent variable explained collectively by all of the independent variables (Miles and Shevlin, 2001).

The convenient model should be tested to assure that the residuals are dispersed randomly throughout the range of the estimated dependent.

The model convenient criterion:

$$F_i^* \leq F_a \tag{17}$$

where, F_i^* is the relation of the chosen disperse S_{2i}^2 and S_{1i}^2 or q_{2i}^2 and q_{1i}^2. S_{1i}^2 Depends on the number of degrees of freedom f_{2i} and f_{1i} of the variables. F_a- table standard (criteria) Poisson distribution for count data.

The disperse S_{2i}^2 and S_{1i}^2 or q_{2i}^2 and q_{1i}^2 is a sum of square difference for ith part of the electrical power system, if it is a linear regression.

However, this is not strictly valid because linear regression is based on a number of assumptions. In particular, one of the variables must be fixed experimentally and/or precisely measurable (Miles and Shevlin, 2001). So, the simple linear regression methods can be used only when we define some experimental variable and test the response of another variable to it (Fox, 2005).

So the S_{2i}^2 and S_{1i}^2 or q_{2i}^2 and q_{1i}^2 are defined experimentally with dependence on the number of degrees of freedom:

$$f_{2i}(f_{2i}^{forS_1^2}) = N;\ f_{2i}(f_{2i}^{forq_1^2}) = N - 1 \tag{18}$$

The weights for the interaction of nonlinear regression based on minimum sum of square difference in the logarithmic and not on sum of square difference:

$$S_{1i}^2 = \frac{\sum_{j=1} (\ln {C_{addij}}/{\bar{C}_{addij}})^2}{N};\ q_{1i}^2 = \frac{\sum_{j=1} (\ln {C_{addij}}/{\bar{C}_{addij}})^2}{N-1}$$
$$S_{2i}^2 = \frac{\sum_{j=1} (\ln {C_{addij}}/{\hat{C}_{addij}})^2}{N-1};\ q_{2i}^2 = \frac{\sum_{j=1} (\ln {\hat{C}_{addij}}/{C_{addij}})^2}{N-2} \tag{19}$$

If the conditions (16) are not realized, the approximation of the Eq. 12 should be changed for another more accurate experimental method.

Finally, the relationship between the additional costs and the absent of the optimal corrections as a function was demonstrated as a mathematical model companioned with its algorithm.

Despite of the interesting results, but we have left unanswered important questions about the functions of the derivative. For instance, it would be very interesting to know plan strategy of control for a certain electrical system in the normal working mode and the contingency plan.

Never the less a lot of subjects can't be covered in one article some of these inquiries will be next works for the authors. Also the problem is to find an optimal schedule that minimizes the long-run average cost per time slot with special case studies for electrical systems (Berry, 1993).

Future research can be built on the broad-based framework by including uncertainty and dynamic quality management decisions. Such extensions would help to address the following issues: What variables (both financial and non financial) can be measured? How can the measured variables be used to provide information (estimates) of latent variable.

CONCLUSIONS

Minimizing the additional embedded operational costs incurred due to the absent of the right and the optimal correction in the electrical power systems by the dispatch control leads to over all running cost minimizing.

This study outlined and discussed the importance of the power operation management as decision makers for the electric power system in the industrial sector where the dispatch operator can avoid the additional embedded operating costs by continuous correction to follow the optimality.

Using this sequence, it was demonstrated an approximation algorithm for the problem. A broad-based conceptual framework for quality costs was developed and the relationships between the various components of quality costs were examined. The relationship between the additional costs and the absent of the optimal corrections as a function was shown in Eq. 13-19.

It was found that quality management decisions related to designing and inspecting are context specific. By using this essential mathematical model, it is easy to integrate actions and online analyses for: management, control, monitoring, maintenance and updating of the electric power quality within the company's strategic planning policies. In other words, the electric power quality will be part of the integrated business strategy of the organization.

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