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Multicriteria optimization of the investment in the auxiliary services of thermal power plants: A case study

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ABSTRACT

Thermal power plants have traditionally operated at rated power as base load, but nowadays they operate at partial loads because of the new situation of the electricity market. These plants have raised their auxiliary services consumption because, in most of the cases, the auxiliaries were not designed to efficiently operate at partial loads. This paper presents a multiple criteria study about the efficiency improvement of the auxiliary services. We consider the economic investment and the net present value, as economic criteria, together with the energy saving criterion. In the multiobjective model proposed, the energy model is validated using several measures taken in a 1100 megawatts coal power plant. Besides, the multiobjective problem associated to the case study considered is solved using evolutionary multiobjective optimization and considering preference information. The results obtained conclude that a significant efficiency improvement of the auxiliary services can be achieved by means of the improvement strategies considered. Indeed, the high net present values reached indicate that the investments required by the different solutions are really profitable from the economic perspective. Therefore, investing money in the efficiency improvement of the auxiliary services represents a very profitable option for improving the operation of power plants at partial loads.

1. Introduction

The new tendencies in the power system organization and the fast-changing technologies in the power industry make necessary using the international experience and activities in the field of the modern economic dispatch problem. Thus, simulation models for evaluating the impacts on economic cost and CO_2 emissions resulting from the introduction of new systems, such as solid oxide fuel cell, into the existing mix of power generation have been developed [1]. Recently, [2] has reported an analysis of the situation of coal fired power plants and has suggested retrofits, technologies, and other modifications to facility operations which offer the potential to improve power plant efficiency and reduce CO_2 emissions.

Traditionally, coal fired thermal power plants have operated at rated power as base load. However, after the liberalization of the power generation market and the integration of a large number of renewable energy power plants, coal fired thermal power plants have been forced to reduce their operating load in order to participate in the frequency regulation. Because of that, nowadays they usually operate at partial loads, and they even stop and start regularly to avoid frequency deviations [3].

Coal fired thermal power plants are characterized by a high energy consumption of the auxiliary services, representing up to 5% of the electricity generated in most of the cases, or even higher than that if a desulphurization plant is needed to achieve the current environmental regulations. Typically, the auxiliary services of many of these power plants were designed to be reliable systems when the plant was operating at full load. At the design phase, they were not especially designed for a notable efficient operation, and, currently, their poor efficiency is particularly acute at partial loads. For example, high efficiency electric motors are rarely used, capacitor banks are hardly ever employed to improve the low power factor of the components, and it is a common practice to use dampers and control valves to regulate the air and water flows in fans and pumps, respectively, instead of using variable speed drives, which are highly recommended since they adjust the flow required to what is actually demanded at each moment. In 2007, [4] provided several recommendations and good practices that apply to station service systems that supply electric power to auxiliary loads for electric power generating stations.

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Nomenclature

f_1	energy saving objective function (in MWh)
f_2	investment cost objective function (in million €)
f_3	NPV objective function (in million €)
i	counter of groups of drives, $i = 1, \ldots, NG$
I	measured current (in A)
I_n	motor nominal current (in A)
j	counter of transformers, $j = 1, \ldots, NT$
NG	number of groups of drives
NPV	net present value of an investment (in million €)
NT	number of transformers
M_i^0	binary parameter, 1 if the motors of drives of group i are of high efficiency, 0 if not
P_i	final active power of drives in group i (in kW)
$P_i^{u,v}$	active power of drives in group i when strategies 1 and 2 are implemented or not, according to $u, v = 0, 1$ (in kW)
P_n	motor nominal power (in kW)
PF	power factor (in %)
Q_i	final reactive power of drives in group i (in kVAR)
Q_i^0	reactive power currently compensated for on drives of group i (in kVAR)
$Q_i^{u,0}$	reactive power of drives in group i when strategy 1 is implemented or not, according to $u = 0, 1$ (in kVAR)
$\overline{QD}_i$	reactive power of drives of group i at full load (in kVAR)
QT_j	reactive power accumulated up to transformer j (in kVAR)
$\widehat{QT}_j$	reactive power accumulated up to busbar of transformer j (in kVAR)
$\overline{QT}_j$	reactive power accumulated up to the busbar of transformer j at full load (in kVAR)
QT_j^0	reactive power currently compensated for on busbar of transformer j (in kVAR)
Q_n	pump/fan nominal flow (in m^3/h)
r	rate of return used in the NPV (in %)
S_n	transformer nominal apparent power (in kVA)
$Speed$	motor speed (in rpm)
U_1	transformer primary nominal voltage (in kV)
U_2	transformer secondary nominal voltage (in kV)
U_{cc}	transformer short circuit voltage (in %)
W_0	transformer no-load losses (in %)
W_{cc}	transformer load losses (in %)
U_n	motor nominal voltage (in kV)
V_i^0	binary parameter, 1 if there are VSDs already installed on drives of group i, 0 if not
$\overline{V_i}$	binary parameter, 0 if it is not possible to install VSDs on drives of group i, 1 if yes
VSD	variable speed drive
XM_i	binary decision variable of group i associated to strategy 1
XQD_i	continuous decision variable of group i associated to strategy 3 (in kVAR)
XQT_j	continuous decision variable of transformer j associated to strategy 3 (in kVAR)
XV_i	binary decision variable of group i associated to strategy 2
XQT_j	continuous decision variable of transformer j associated to strategy 3 (in kVAR)
XV_i	binary decision var. of group i associated to strategy 2
$\bar{\mathbf{z}}$	solution selected by the DM
$\mathbf{z}^1$	solution which individually maximizes the energy saving
$\mathbf{z}^2$	solution which individually minimizes the investment cost
$\mathbf{z}^3$	solution which individually maximizes the NPV
μ	efficiency of current motors
μ_{new}	efficiency of new motors

While a number of studies related to thermodynamics try to increase the thermal efficiency of power plants through the thermal enhancement of the turbine or the boiler (for example, [5] showed that an appropriate design of heat recirculation via thermoelectric converter may result in a significant increase in the efficiency of the system and [6] carried out an exergy analysis of the turbine, the boiler and the condenser), relatively little attention has been paid to the improvement of the efficiency of the auxiliary services. In this regard, [7] analyzed the performance of some efficiency improvements that can be carried out in the auxiliaries, such as the use of variable speed drives and automation systems, and [8] studied the improvement of the thermal efficiency in a nuclear power plant by means of auxiliary-condenser circulating-water flow reduction, circulating-water discharge diversion to the main condenser and feed water heater drain recycling. Moreover, optimization algorithms have been developed in order to solve electric equipment configuration problems in a power plant. For example, by using these methods, problems such as cost minimization of electric equipment configuration and the corresponding cabling and parallel operation of multiple transformers have been solved [9].

A priori, auxiliary services may not be regarded as the most interesting elements to increase the efficiency in a thermal power plant. But this paper presents a multiobjective optimization study which shows that the efficiency improvement of the auxiliary services does represent a very interesting and economically profitable alternative to raise the overall efficiency of thermal power plants and, thus, to reduce the operation costs. For that, we have identified interesting retrofits of the auxiliaries and we have mathematically modeled the problem we are dealing with, considering both energy and economic criteria. The multiobjective optimization model proposed has been designed so that it can be applied to the auxiliaries of any power plant, and it has been validated by the measures taken in the auxiliary services of a 1100 MW power plant of the Endesa Generation S.A. company, mainly constituted by pumps and fans drives, which represent up to 50 MW of the total generated power of the plant.

Besides, in this paper, we solve the multiobjective problem associated to the auxiliaries of this specific case study together with a real engineer (the decision maker (DM)), and we analyze the results obtained from the economic and energy perspectives. Because of the main features of the problem, it has been solved using evolutionary multiobjective optimization, whose algorithms simulate the process of natural evolution in order to find a set of solutions approximating the whole set of Pareto optimal solutions. With this information, we have analyzed the conflict degree among the objective functions considered. But, in order to ease the selection of the final solution, a preference-based evolutionary algorithm has been also applied. By means of this algorithm, the search for the most preferred solution is concentrated into the most interesting subset of Pareto optimal solutions, according to the preferences of the DM.

This paper is organized as follows. Section 2 describes the case study we have considered and the multiobjective optimization model proposed. Also, we introduce general concepts of multiobjective optimization and the algorithms used for solving our