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WIND TURBINE CONTROL TUNING WITH MULTI-OBJECTIVE OPTIMISATION TECHNIQUES

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Abstract. *Multi-objective optimisation techniques have shown to be a valuable tool for control engineering systems. Such techniques offer a suitable framework in order to analyse benefits and drawbacks of a given control structure in an overall sense, by analysing trade-off surface. In this work, we use a reliability optimisation based approach with multi-objective optimisation for a wind turbine control loop. Obtained results validate this approach as useful, when compared with other controllers.*

Keywords: *Controller tuning, multi-objective optimisation*

1. INTRODUCTION

Dealing with real world engineering problems often comes with facing multiple and conflicting objectives and requirements. When dealing with controller tuning applications, several requirements are considered, in order to improve the overall performance of the control loop.

Multi-objective optimisation can handle such an issue, by means of a simultaneous optimisation of the design objectives Miettinen (1999). At the end of this process, a potential set of solutions, the Pareto front, are calculated. In this set of solutions, there is not a best solution, but a preferable solution. This meaning that several solutions are calculated, with different trade-off between conflicting objectives and the engineer will select among them the most preferable for the problem at hand.

In this paper, we will apply a multi-objective optimisation design procedure for controller tuning Reynoso-Meza *et al.* (2014) in order to improve the overall performance of a control loop of a wind turbine. The remainder of this paper is as follows: in Section 2 a brief background on multi-objective optimisation is given, as well as the algorithms and tools used. In Section 3, the case problem is described and results are described. Finally, some conclusions are given.

2. BACKGROUND

2.1 Multi-objective optimisation

As referred in Miettinen (1999), a MOP with m objectives[1], can be stated as follows:

$$\min_x J(x) \quad = \quad [J_1(x), \ldots, J_m(x)] \tag{1}$$

subject to:

$$K(x) \leq 0 \tag{2}$$

$$L(x) = 0 \tag{3}$$

$$\underline{x_i} \leq x_i \leq \overline{x_i}, i = [1, \ldots, n] \tag{4}$$

where $x = [x_1, x_2, \ldots, x_n]$ is defined as the decision vector with $\dim(x) = n$; $J(x)$ as the objective vector and $K(x)$, $L(x)$ as the inequality and equality constraint vectors respectively; $\underline{x_i}, \overline{x_i}$ are the lower and the upper bounds in the decision space.

[1] A maximisation problem can be converted to a minimisation problem. For each of the objectives that have to be maximised, the transformation: $\max J_i(x) = -min(-J_i(x))$ could be applied.

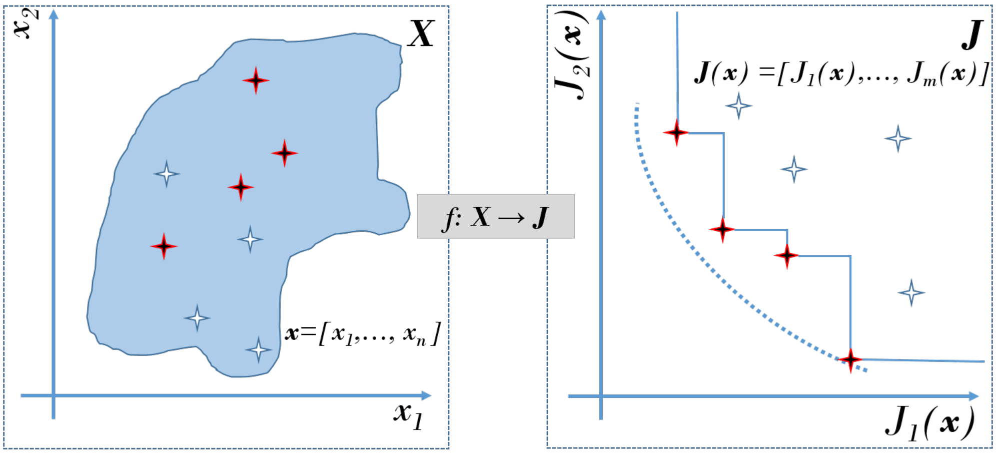

Figure 1. Pareto optimality and dominance concepts for a min-min MOP. Dark solutions are non-dominated solutions which approximate (solid line) the Pareto front (dotted line) in the objective space J. Source: Carrau *et al.* (2017)

It has been noticed that there is not a single solution in MOPs, because there is not generally a better solution in all the objectives. Therefore, a set of solutions, the Pareto set X_P, is defined. Each solution in the Pareto set defines an objective vector in the Pareto front J_P (See Figure 1). All the solutions in the Pareto front are a set of Pareto optimal and non-dominated solutions:

- Pareto optimality Miettinen (1999): An objective vector $J(x^1)$ is Pareto optimal if there is not another objective vector $J(x^2)$ such that $J_i(x^2) \leq J_i(x^1)$ for all $i \in [1, 2, \ldots, m]$ and $J_j(x^2) < J_j(x^1)$ for at least one j, $j \in [1, 2, \ldots, m]$.
- Dominance Coello and Lamont (2004): An objective vector $J(x^1)$ is dominated by another objective vector $J(x^2)$ iff $J_i(x^2) \leq J_i(x^1)$ for all $i \in [1, 2, \ldots, m]$ and $J_j(x^2) < J_j(x^1)$ for at least one j, $j \in [1, 2, \ldots, m]$. This is denoted as $J(x_2) \preceq J(x_1)$.

It is important to notice that most of the times we rely only in Pareto front and set approximations, J_P^*, X_P^*.

A multi-objective optimisation design procedure (MOOD) is used, as described inReynoso-Meza *et al.* (2014). It has three main steps:

1. Multi-objective optimisation problem: design objectives are stated, as well as decision variables.
2. Multi-objective optimisation Process: that is, approximating the Pareto front.
3. Multi-criteria Decision Making stage: a given solution is selected, after and analysis of the approximated Pareto front.

2.2 Controller tuning as a multi-objective problem

A basic control loop is depicted in Figure 2. It comprises transfer functions $P(s)$ and $C(s)$ of a process and a controller respectively. The objective of this control loop is to keep the desired output $Y(s)$ of the process $P(s)$ in the desired reference $R(s)$.

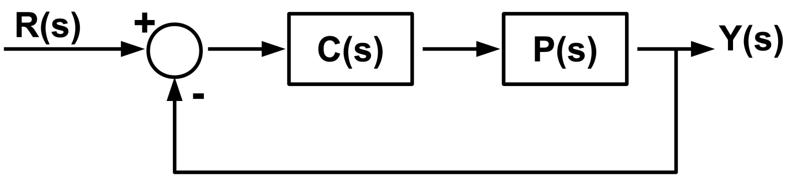

Figure 2. Basic control loop.

The control problem consists in selecting adequate parameters of the proposed controller $C(s)$ in order to achieve a desirable performance of the process $P(s)$ in the control loop as well as robust stability margins. As commented by

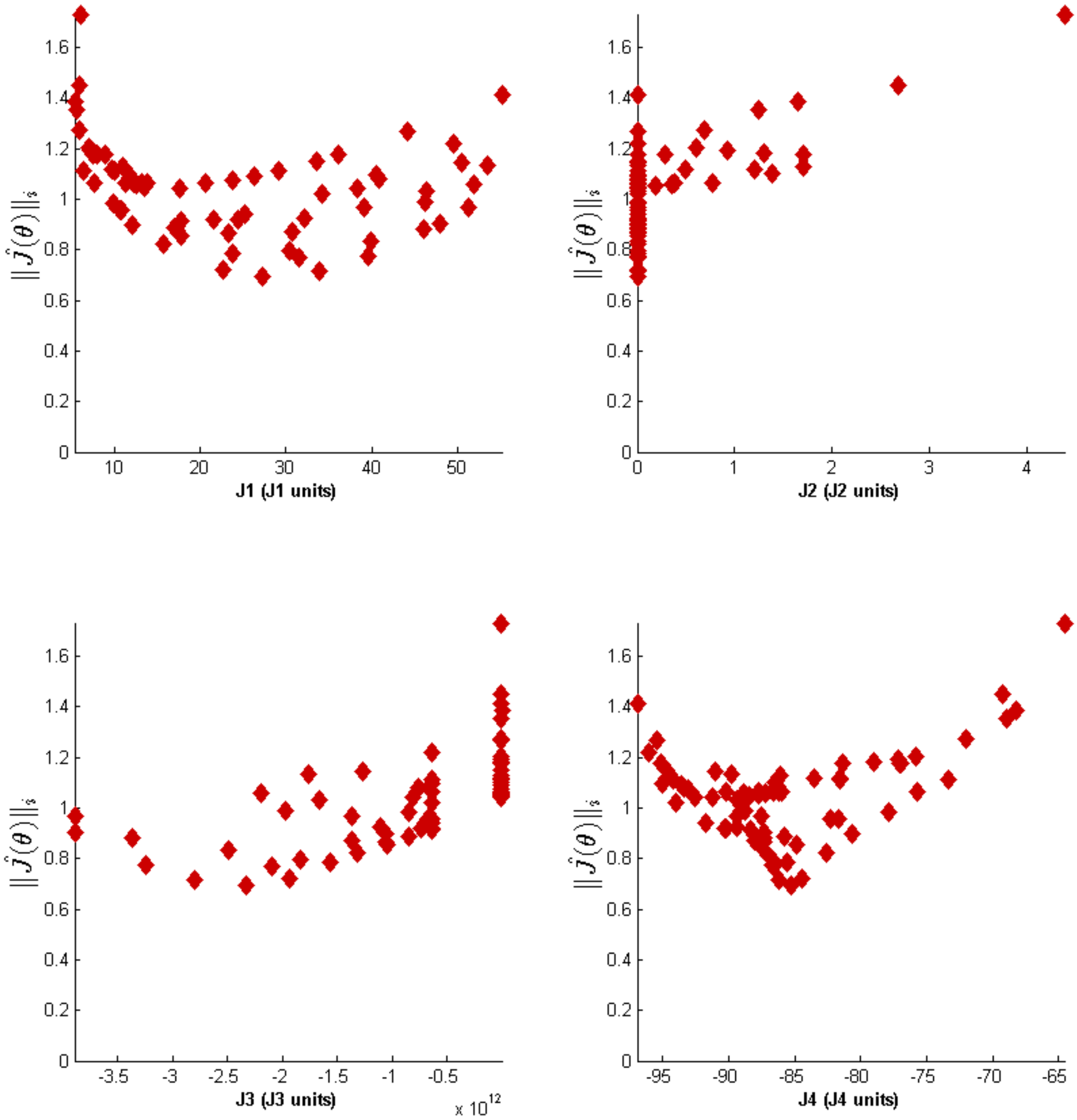

Figure 3. Approximated Pareto front.

Garpinger *et al.* (2014), conflicting objectives may appear, when seeking a good performance and a desirable robustness level; for this reason, MOO techniques could be appealing for controller tuning.

3. TEST

The following transfer function is considered, taken from Carrillo-Ahumada *et al.* (2016); Moradi and Vossoughi (2015)

$$P(s) = \frac{s}{J_t s^2 + C_t s + K_t} \tag{5}$$

Plant variables J_t, C_t and K_t are uncertain parameters, but it is know that there are in the interval $\pm 25\%$ from the nominal values $[16, 52, 52]$ respectively. A modified PID controller is proposed:

$$C(s) = k_p \left(1 + \frac{1}{T_i s} + T_d s\right)\left(\frac{1}{s}\right) \tag{6}$$

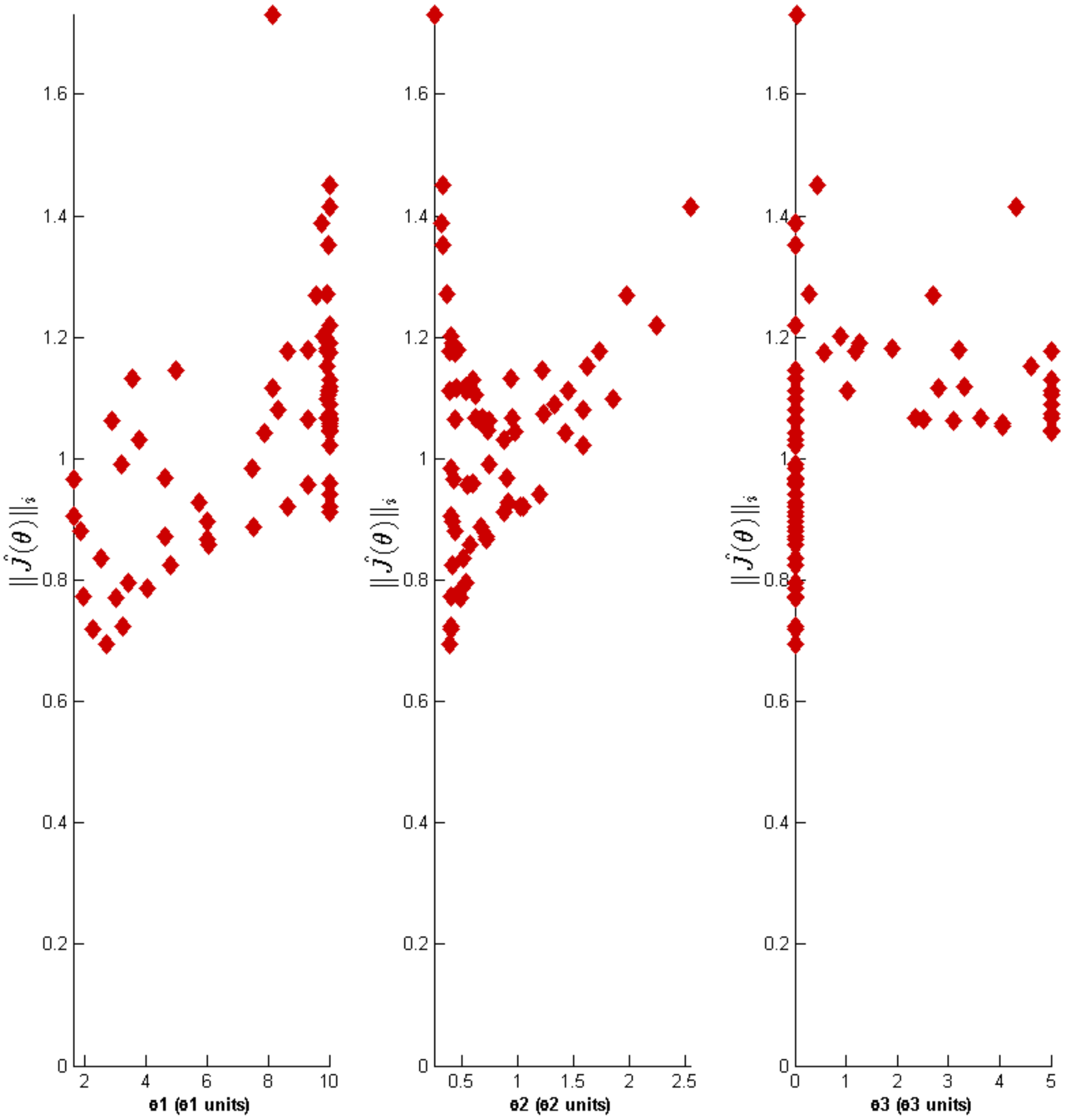

Figure 4. Approximated Pareto set.

In this case, decision variables are the tuning parameters of a given controller. Design objectives are related with the expected performance of the control loop. The following MOP statement is optimised:

$$\min J(x) = [J_1(x), J_2(x), J_3(x), J_4(x)] \tag{7}$$

Given a set of variable plant in the specified interval, $J_1(x)$ is the median of the settling time, $J_2(x)$ is the median of the overshoot and $J_3(x)$, $J_4(x)$ gain and phase margin respectively. In all cases, closed loop stability is a constraint. Results of the optimisation procedure are depicted in Figure 1 and 2 (Pareto Front and Pareto set, respectively). From such Pareto front approximation, a design alternative is selected. Further control tests with other tuning techniques are compared in Table 1 (with a different set of plants used in the optimisation process).

1. Multi-objective Optimisation Process: the sp-MODE algorithm Reynoso-Meza *et al.* (2010). It is used due to its performance for controller tuning applications Meza *et al.* (2016).

2. Multi-criteria Decision Making stage: Level Diagrams are used Blasco *et al.* (2008); Reynoso-Meza *et al.* (2013); Blasco *et al.* (2016).

Table 1. Further control tests.

Design Objective	$J1$	$J2$	$J3$	$J4$
This work	9.79	0.00	$-8.4e11$	-77.90
Carrillo-Ahumada *et al.* (2016)	8.52	0.00	$-2.5e06$	-73.60
Moradi and Vossoughi (2015)	26.61	0.00	$-6.1e05$	-92.54

4. CONCLUSIONS

In this paper, MOOD procedure techniques were used to tune the parameters of a PID controller, in order to improve the overall performance of a wind turbine control loop using a reliability based approach. Obtained results validate this approach as practical and useful.

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