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Adaptive fuzzy PI controller with shifted control singletons

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ABSTRACT

It is well known the fact that the design of a fuzzy control system is based on the human expert experience and control engineer knowledge regarding the controlled plant behavior. As a direct consequence, a fuzzy control system can be considered as belonging to the class of intelligent expert systems. The tuning procedure of a fuzzy controller represents a quite difficult and meticulous task, being based on prior data regarding good knowledge of the controlled plant. The complexity of the tuning procedure increases with the number of the fuzzy linguistic variables and, consequently, of the fuzzy inference rules and thus, the tuning process becomes more difficult. The paper presents a new design strategy for such expert fuzzy system, which improves their performance without increasing the number of fuzzy linguistic variables. The novelty consists in extending the classic structure of the fuzzy inference core with an intelligent module, which tunes one of the control singletons, providing a significant simplification of the design and implementation procedure. The proposed strategy implements a logical, not physical, supplementation of the linguistic terms associated to the controller output. Therefore, a fuzzy rules set with a reduced number of linguistic terms is used to implement the expert control system. This logical supplementation is based on an intelligent algorithm which performs a shifting of only one of the control singletons (the singleton associated to the SMALL_ linguistic variable), its value becoming variable, a fact that allows an accurate control and a better performance for the expert control system. The logic of this intelligent algorithm is to initially provide a high controller output, followed by a slowdown of the control signal near to the operating set point. The main advantage of the proposed expert control strategy is its simplicity: a reduced number of linguistic terms, combined with an intelligent tuning of a single parameter, can provide results as accurate as other more complex available solutions involving tuning of several parameters (well described by the technical literature). Also, a simplification of the preliminary off-line tuning procedure is performed by using a reduced set of fuzzy rules. The generality of the proposed expert control strategy allows its use for any other controlled process.

1. Introduction

The fuzzy controllers represent an efficient solution for many control problems, being based on several rules conceived on the basis of plant handling experience. They are most suitable for the control of high non-linear plants or those for which an analytic model is unavailable (Chahkoutahi, MoradiPour, Gholami, Ashja, & Rahimi, 2015; Lilly, 2010; Nahlovsky, 2015; Zadeh, 2015). Such a parameterized analytical model (especially linear) would allow the design of a classic control law (such as PI, PID, minimum variance, etc). In contrast with a control system based on conventional techniques, the fuzzy control involves prior data (qualitative and quantitative) regarding the controlled plant (which have a non-linear characteristic and is unidentifiable through an analytical model). The basic data used for the design of a fuzzy controller has as a starting point the experience of a human expert regarding the manual operation of the considered plant. Starting from input/output measurements, the following steps are required in a first stage, aiming the data fuzzification, (Lilly, 2010; Zadeh, 2015):

- The selection of input/output variables of the expert controller and, accordingly, the type of fuzzy controller (fuzzy PI, PID, etc);
- The setting of the number of the linguistic terms, completely covering the variation ranges of the previously chosen input/output variables;
- The sizing of these linguistic terms, by setting appropriate values in accordance to their variation ranges.

In the present paper, a PI type fuzzy controller (with integration on output) is chosen for analysis, the input variables being the system output error, respectively the error derivative. For each

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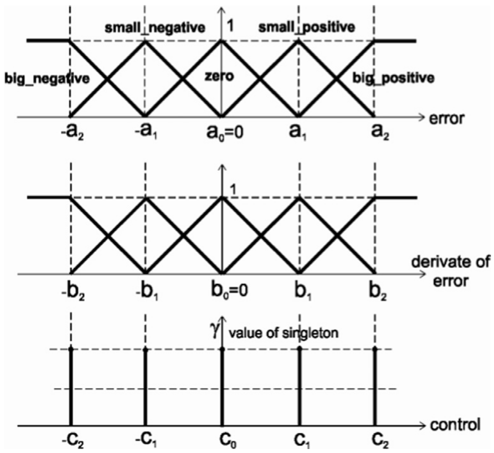

Fig. 1. Fuzzy membership functions.

of those, five linguistic variables are considered, their corresponding membership functions being of triangular shape, respectively of trapezoidal shape for the extreme variation ranges. For the controller output, singleton type membership functions are considered (see Fig. 1). Also in the case of the controller output, 5 linguistic variables are considered related to the 5 variation ranges of the chosen variables (*big_negative, small_negative, zero, small_positive, big_positive*). The set-up of those variables (as a last step of the data fuzzification procedure) represents in fact the tuning of the fuzzy controller, an operation that is one of the main subjects of the present paper. Based on the human expert experience and control engineer knowledge regarding the qualitative and especially the quantitative plant behavior, the tuning procedure of a fuzzy control system is quite a laborious task (Gomez-Ramirez, 2007; Gomez-Ramirez, Melin, & Castillo, 2011; Mudi, & Mitra, 2012; Pandey, 1997). The performance of a fuzzy control system depends on the number of fuzzy linguistic terms and range of the membership function. The technical literature presents many complex techniques for on-line tuning a fuzzy controller (based on gradient method, genetics algorithms, neural networks, neuro-fuzzy, even fuzzy logic again, etc), involving many adjustable parameters (Ding, Liwei, Jinghao, & Qingling, 2015; Hoang, 2016; Krzysztof, 2016; Manentia et al., 2015; Mester, 2014; Nasser, Sharkawy, & Soliman, 2015; Uddin et al., 2015; Zadeh, 2015). Other previous researches of the authors were also focused on developing and tuning expert fuzzy system designed to control plants from diverse domains, including power plants (Budisan, Prostean, Robu & Filip, 2007; Filip, Prostean, Szeidert, Balas, & Prostean, 2006; Filip, Szeidert, & Prostean, 2014; Tirian, Filip, & Prostean, 2013; Tirian, Filip, & Prostean, 2014). One of the main goals of these researches was to improve and simplify the tuning strategy of such expert control system (especially with application to the power systems).

A preliminary empirical off-line tuning (based on a priori data) is supposed to be performed, aiming the achievement of good results, in accordance with the imposed qualitative requirements. The question that arises is the following: Is there a possibility to perform a more precise tuning that would ensure even better control performances? In other words, can this “final” tuning to provide maximum performances (by a proper adjustment of the linguistic terms)? When can the tuning procedure be considered finished? Obviously, related to the last question, a possible response would be: the tuning is finished when the controlled output performances are satisfying in relation to imposed criteria. But, are these performances best achievable, reported to the classic control quality indicators? This incertitude will persist even in the moment when the finalization of the off-line tuning procedure is decided. This is the kind of questions that the present paper will try to answer to, overcoming the preconceived idea that good knowledge regarding the operating features of a controlled process could be sufficient to make a facile and fast tuning of a fuzzy controller. Furthermore, although the data fuzzification represents the first step in order to implement a fuzzy controller and it is accomplished off-line, after testing the fuzzy controller, this operation is resumed again (of course, with other values associated to the linguistic terms), until the required quality indicators of the expert control system are achieved. Practically, the tuning procedure of a fuzzy controller is made through iterative attempts, until a retuning of its parameters does not lead to significant improvements of its control performances (Mendes, Araujo, & Souza, 2013).

For some inputs/outputs of the controller or of the controlled plant, their evolution is easy to be understood and interpreted by the control system designer. But for others, their interpretation is quite difficult. For example, if the controlled plant output presents a too long settling time, logically the values of the singletons associated to the controller output must be increased. If an overshoot occurs, the values of these singletons must be decreased. However, taking into account a variable such as the error’s derivative (supposing that the controller inputs are the system output error and the error derivative), it is quite difficult to talk about a human expert’s knowledge regarding its evolution. Maybe the error represents a concept easily interpretable by the control system designer, but such a thing cannot be stated about the derivative of error.

There naturally arises the question whether it is possible to establish some general rules or recommendations, or even an algorithm that would assist the tuning operation of a fuzzy controller. The present paper proposes such useful rules applicable to a PI fuzzy controller, having the output error and error derivative as input variables, respectively the singleton linguistic term associated to the controller output variable. Although tested on a particularized fuzzy control system, with application to control of induction generator terminal voltage, this fact does not limit the generality of the proposed rules in the context of any controlled plant. Furthermore, the complexity of the tuning procedure of a fuzzy controller increases when increasing the number of linguistic variables. For this reason, a simpler controller structure was chosen, with only 5 linguistic terms (simplifying the tuning procedure), even if its control precision is inferior to the one with 7 or more linguistic variables. Therefore, a PI fuzzy controller with only two input variables was chosen (unlike a PID fuzzy controller requiring three input variables, but also having better performances) (Santos, Domido, & Cruz, 1996). The paper proposes, as it will be presented in the following chapters, a logical mechanism that allows (after a preliminary off-line tuning process of the controller) an on-line adaptation of a parameter, so that the controller behaves as if the number of linguistic terms associated to the controller output were increased from 5 to 7. In the context of disturbances rejection, such an approach provides better performances for the control system.

2. Off-line tuning scenario

Several study cases have been analyzed for the following set of 5 linguistic variables associated to the input variables (error and error derivative), respectively to the controller output variables: (*big_negative*), (*small_negative*), (*zero*), (*small_pozitive*), (*big_pozitive*). As already stated, the triangular shape was chosen for membership functions associated to input variables (except for its extremities for which trapezoidal shapes were chosen), respectively singleton shape for the controller output (Fig. 1).