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Support vector regression methodology for wind turbine reaction torque prediction with power-split hydrostatic continuous variable transmission

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ABSTRACT

Nowadays the use of renewable energy including wind energy has risen dramatically. Because of the increasing development of wind power production, improvement of the prediction of wind turbine output energy using classical or intelligent methods is necessary. To optimize the power produced in a wind turbine, speed of the turbine should vary with wind speed. Variable speed operation of wind turbines presents certain advantages over constant speed operation. This paper has investigated power-split hydrostatic continuously variable transmission (CVT). The objective of this article was to capture maximum energy from the wind by prediction the optimal values of the wind turbine reaction torque. To build an effective prediction model, the polynomial and radial basis function (RBF) are applied as the kernel function of Support Vector Regression (SVR) for prediction of wind turbine reaction torque in this research study. Instead of minimizing the observed training error, $SVR_{\_poly}$ and $SVR_{\_rbf}$ attempt to minimize the generalization error bound so as to achieve generalized performance. The experimental results show that an improvement in predictive accuracy and capability of generalization can be achieved by our proposed approach. Results show that SVRs can serve as a promising alternative for existing prediction models.

1. Introduction

Due to the high requirement for renewable energy sources the development of wind energy plants has made a huge progress during the last years. Still, it remains a particular challenge to ensure predictable operation and high performance throughout the entire period of operation and to minimize costs at the same time. Despite good existing concepts, new solutions that suggest fundamental changes and improvements are developed constantly [1].

Wind turbine systems are characterized by their unpredictable rotation in different regions and maximum performance under optimal rotor rotation [2]. To ensure the optimal rotor rotation of wind turbine generators the drive train of those machinery requires a continuously variation of the transmission ratio without disturbance of tractive forces, high tractive forces at low speed and fast reversing operation [3–5].

In recent years, the progression of the transmission systems was addressed to increase optimal wind turbine rotor rotation without cost of efficiency [6]. These objectives incorporate the use of continuous transmissions that allow the elimination of the shifting gears, which is sometimes tiresome [7]. Current technology provides some solutions for continuous variable transmission (CVT): the hydrodynamic, the hydrostatic, the mechanical and the electrical [8–10]. The hydrodynamic transmission is not useful for these applications because its transmission ratio is not controllable by the user and it has a good efficiency only at high speeds. The hydrostatic transmission can easily control the speed, but with a very low efficiency because of the double energy conversion occurring in it [11]. The mechanical transmission is characterized by high efficiency, although sometimes with limits of power and

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speed range. This requires the use of a mechanical gearbox further downstream. Electric transmission, although especially suitable for speed control, sometimes has unsatisfactory levels of performance and still high costs.

From these examinations, it can be assumed that the efficiency requirements cannot be satisfied only by a directly coupled CVT [12,13]. For this reason, a new type of transmission was designed, in which the power is transmitted partially via a mechanical path, and partly through a CVT. The two powers are then summed by means of a planetary gearing. In this way, the transmission is still a continuously variable transmission but with efficiency higher than that of the CVT taken independently, since the transmission efficiency can be determined as the weighted efficiency of the two paths. This type of transmission is called power-split transmission [14,15]. The power-split configuration presently producing the best arrangement between efficiency and cost seems to be the hydro mechanical power-split transmission, where the variable element is the hydrostatic transmission. It offers significant gain potential thanks to its many possible configurations [16].

The use of power-split hydrostatic CVTs also called hydro mechanical power-split transmission combines the advantages of a plain continuously variable hydrostatic transmission with high power density at low speeds with the high efficiency of a power-split drive at higher speeds [17,18]. That means in the context of wind turbines good efficiency at wind variation, including hydrostatic reversing, combined with the efficiency of a power-split drive at rotation speeds. The possible speeds in each driving range depend on the system design, and mostly on the size and actuation range of the hydrostatic systems [19,20]. The concept of power-split hydrostatic CVTs naturally needs sophisticated electronic control architecture, since the control and the coordination of the hydraulic and the mechanical parts of the CVT cannot be obtained by mechanical elements only. The electronic control system depends on a number of measurable values such as the speed of the combustion engine and hydrostatic motor, displacement of the hydrostatic pump and motor, different oil pressures in the closed circuit and the clutches, and the position of the drive pedal.

The objective of this article is to capture maximum energy from the wind or operate the turbine with power-split hydrostatic CVT in peak coefficient of power. The desired optimal turbine characteristics can be achieved by controlling the reaction torque of the turbine rotor. When the wind speed changes the torque due to the wind also changes and hence the acceleration. The reaction torque is provided by the generator and this can be controlled by the operator. To control the reaction torque it is reasonable to predict the torque optimal values. Two input parameters were chosen (wind speed and rotor speed) to correlate with reaction torque optimal values. Since it is non-linear relationship a soft computing technique was used.

Artificial neural networks (ANNs) are being extensively applied to various areas to overcome the problem of non-linear relationships and predictions [21–27]. Recently, improved version of ANNs which is called Support Vector Machines (SVMs) has gained importance in forecasting problems related to environment [28–34]. There are two main categories for support vector machines: support vector classification (SVC) and support vector regression (SVR). SVM is a learning system using a high-dimensional feature space [35–39]. The Support Vector Regression (SVR) algorithms specifically developed for regression problems are appealing algorithms for a large variety of regression problems, since they do not only take into account the error approximation to the data, but also the generalization of the model, i.e., their capability to improve the prediction of the model when new data are evaluated by it [40–46]. SVR is based on statistical learning theory and a structural risk minimization principle, which has been successfully used for non-linear system modeling [47–51].

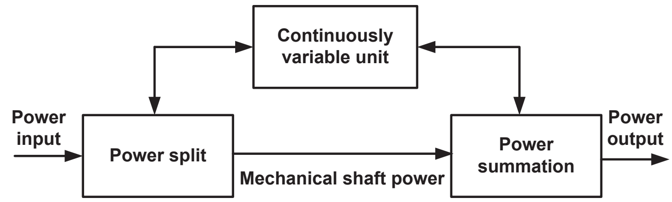

Fig. 1. Power-split CVT.

A Kernel function can be utilized to form qualified function which is used SVM. In article Ref. [52] has pointed out that SVM shows its high performance in accuracy of prediction for stream flow. Because of this, SVM has the advantage that it can handle the classes with complex non-linear decision boundaries. Furthermore, researchers have demonstrated that the use of SVR in predicting of hydrological modeling and pointed out the positive performance of the RBF (radial basis function) [53,54]. Article [55] proposed different Kernels in SVR to rainfall–runoff modeling and validated that the radial basis function (RBF) outperforms other Kernel functions. Hence, the RBF and polynomial function are applied as the Kernel function for prediction of wind turbine reaction torque in this research study. The accuracy of an SVM model is largely dependent on the selection of the model parameters. However, structured methods for selecting parameters are lacking. Consequently, some kind of model parameter calibration should be made.

To solve the problem of choosing parameters in SVM, the support regression machine adopts to choice of a kernel requires setting up of kernel-specific parameters, optimum values of the regularization parameter C and the size of the error-insensitive zone e. In our scheme, the SVR for prediction of the optimal values of wind turbine reaction torque was used. The SVR_rbf and SVR_poly were examined: the first one is radial basis function and the next is polynomial function. The traditional ANN and adaptive neuro fuzzy inference system (ANFIS) [56–59] were also investigated for comparison.

2. Experimental setup and procedure

2.1. Principle of hydrostatic–mechanical power-split CVT

Mechanical input energy with hydrostatic–mechanical power-splitting transmission is converted into mechanical and hydrostatic energy and then is reconverted into mechanical energy before leaving at the output. Fig. 1 shows the basic principle structure of a hydrostatic mechanical power-split drive.

The basic idea is to split the input power into two parts, with one part the power send through a variable ratio hydrostatic path, with the remainder part of the power into a constant ratio mechanical part with higher efficiency. The two part of power are then summed up in a mechanical differential gear or a planetary gear.

2.2. Differential mechanical–hydrostatic transmission

Differential mechanical–hydrostatic transmission uses a hydrostatic circuit to obtain a continuous variable transmission ratio and to make independent rotational speed of the turbine from electric generator. The electric rotor rotates at a constant speed while the turbine rotates at variable speed. So, it can be directly connected to the net without the converter.

Generally the power losses of a hydraulic system are higher than those of a mechanic one for the same power and transmission ratio.