Title: Fault Detection, Supervision and Safety for Energy Conversion Systems: Wind Turbines and Hydroelectric Plants

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Abstract: The motivation for this article comes from a real need to have an open discussion about the challenges of fault detection and supervision for very demanding systems, such as energy conversion systems. These features represent the key characteristic to identify possible malfunctions affecting the system (*i.e.* the so-called faults) and, at the same time, the capability to continue working while maintaining power conversion efficiency, if proper countermeasures are adopted. Moreover, the safety issue has begun to stimulate research and development in a wide range of industrial communities particularly for those systems demanding a high degree of reliability and availability, such as wind turbines and hydroelectric plants. In fact, once the faults are promptly detected and compensated, the system will be able to maintain specified operable and committable conditions, and at the same time should avoid expensive maintenance works. For very large installations a clear conflict exists between ensuring a high degree of availability and reducing costly maintenance, thus justifying the solutions addressed in the proposed contribution.

Article

With the continuing decrease in the stock of global fossil fuels, issues of security of supply, and pressure to honour greenhouse gas emission limits, much attention has turned to renewable energy sources to fulfil future increasing energy needs. Wind energy, now a mature technology, has had considerable proliferation compared to other sources, such as biomass, solar, and hydraulic energy systems. Hydraulic power provides previously untapped energy potential, and hydroelectric systems can show some variability properties, especially when combined with wind energy.

One common misconception in effective renewable energy conversion system design is that converters must be optimally efficient. However, since the resource itself (wind and hydraulic power) is free, the main objective is to minimise the converted cost of the renewable energy *i.e.* the cost per kWh, taking into account the lifetime costs (capital, operational and commissioning/decommissioning costs) as well as energy receipts (value of energy sold). Nevertheless, for a given capital cost, maximising the energy receipts (assuming relative insensitivity of operational costs) is an important economic objective and control system technology has an important role to play in this regard. In an ideal world, one should consider the design of a complete system from the top down. However, the discipline-specific experts usually design physical systems and control engineers, working in collaboration with the discipline-specific experts, then address the control problem in a subsequent step. Such an approach, though prevalent in the bulk of industrial applications of control, is non-optimal, even if there are some notable exceptions.

Recent studies suggest a strong interaction between the fundamental design of renewable energy conversion machines and the systems used to achieve supervision and fault diagnosis tasks [1, 2]. In any case, given the relatively low cost of supervision systems (developed via computer algorithms and software) compared to the cost of the renewable energy converters, the recent focus of research has been on increasing the energy conversion capacity of a given wind turbine or hydroelectric system device. However, this relatively simple implementation modality masks both the capability of supervision systems and the high level of engineering underpinning the development of suitable fault diagnosis algorithms. For example, many high-performance model-based supervision and fault diagnosis methods require an accurate mathematical model of the system to be controlled and a significant number of man-hours can be absorbed in modelling. Nevertheless, there is usually a good case to be made for the incorporation of this technology to improve the performance (both technical and economic), reliability and safety of systems. By taking into account commonalities and contrasts in particular for wind turbines and hydroelectric systems, the role that computer science engineering can play in making energy conversion systems can be made more competitive and effective [1, 2].

There are a number of economic issues associated with the introduction of supervision and fault diagnosis systems for improving the safety and reliability of renewable energy devices that need to be considered. One important factor is that many wind turbine and hydroelectric devices are situated in relatively remote and/or inaccessible areas, with consequent implications for maintenance. As a result, the implemented supervision and fault diagnosis systems should be reliable and there is a need for safety features. In addition, any changes in the working conditions associated with energy conversion systems need to be considered and these may impact operational cost via additional maintenance requirements.

Both wind turbines and hydroelectric systems exhibit nonlinear behaviour and are required to operate over a wide range of excitations [1, 2]. These energy conversion systems also have particular physical constraints (displacements, velocities, accelerations and forces) that must be strictly observed if such systems are to operate effectively and have economically attractive useful operational lifetimes. The challenges for wind turbines and hydroelectric systems present common and different requirements related to renewable power conversion efficiency into electric energy. In general, within the issues considered here, power conversion is converting renewable sources to electric energy, also regulating the voltage and frequency. Therefore, a power converter is an electro-mechanical device for converting wind/hydraulic energy to electrical energy. The power converter includes electrical machinery that is used to convert and control both frequency and voltage.

With this view, commonalities and contrasts for wind and hydraulic energy systems are briefly outlined in the following. On one hand, even if hydraulic energy systems are well established and even more common than wind installations, the supervision and the fault diagnosis problems for wind turbines have received much more attention in the last decades [1, 2]. In addition, the fault tolerant control problem for wind turbines has been recently analysed [1]. In general, these supervision and fault diagnosis methods are classified into two types, *i.e.* passive and active schemes. Passive solutions are designed to be robust against a class of presumed faults. In contrast to them, active approaches react to the system component failures actively by proper reconfiguring actions so that the stability and acceptable performance of the entire system can be maintained. The main difference between active and passive schemes is that an active design relies on a fault diagnosis system, which provides information about the faults. In the considered case, the fault diagnosis system provides the estimation of the unknown input (fault) affecting the system under control. The knowledge of the fault allows the active supervision design system to reconfigure the current state of the system. On the other hand, the passive scheme does not rely on a fault diagnosis algorithm, but is designed to be robust towards any possible faults. This is accomplished by designing a supervision system that is optimised for the fault-free situation, while satisfying some graceful degradation requirements in the faulty cases. However, with respect to a robust design, the passive strategy provides reliable controllers that guarantee the same performance with no risk of false fault detection [1].

On the other hand, few works analysed the model-based design of supervision and fault diagnosis strategies when applied to hydroelectric plants, as considered *e.g.* in [2]. In fact, as a mathematical model is needed for the description of the system behaviour, precise modelling for these processes could be difficult to achieve in practice. There are several works that discuss the modelling of hydroelectric processes with their supervision and fault diagnosis design, as shown in [2]. These works consider the elastic water effects, though the nonlinear dynamics are linearised at an operating point. Other papers considered different mathematical descriptions with the techniques to control the power systems. Moreover, linear and nonlinear plants with various water column effects and supervision solutions are also considered.

Therefore, the focus should be on the identification of the aspects that might be common with a view to utilising some ideas, born in the wind turbine domain, within the other regarding hydroelectric plants. These issues have begun to stimulate research and development in the wider control community in each domain, and interesting results have been obtained. In particular, a proper mathematical description of these energy conversion systems should be able to capture the complete behaviour of the process under monitoring, thus providing an important impact on the design of the supervision and the fault detection systems themselves [1, 2].

Finally, it is worth noting that when the safety-critical level of the process under diagnosis is relatively high, the implementation of supervision and fault detection methodologies may be even cheaper and more reliable than the cheapest and simplest multiple redundant hardware sensor systems [1, 2].

References

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