PO.ID 039

Enabling Energy Output Optimization with Controls, Service Scheduling & Spares Management

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Abstract

Energy output optimization is a key driver for wind turbine manufacturers, developers, and wind park owners/operators. The goal is to maximize the return by tinkering with the key elements of the Cost of Energy (COE) equation. Specifically, it is important to develop and implement solutions which address the following areas:

- Increase annual energy production (AEP).
- Regulating wind turbine / wind farm power output for delivery of power to the electric grid based on price optimal timing.
- Reduce O&M costs.
- Extend life of wind parks to minimize unscheduled maintenance.
- Streamline spare parts inventory in accordance with identified service requirements and known upcoming component replacements.

Solutions

The architecture of a power plant control system should have the ability to regulate turbine performance while delivering a maximum level of price-optimized electricity. Areas which require further development include:

Turbine operational envelope definition

- Forward-looking operational envelope definition based on component life consumption models does not appear to be widely known or discussed in the patent literature. This is a multi-variable analysis approach, as opposed to the more simplistic approaches offered in the prior art which analyze one variable at a time and compare the analysis results to a predicted model.

Turbine control within operational envelope

- Model-based control seems to be fairly well known in the wind industry at this point, but model predictive control is relatively unknown and underutilized in the wind industry. There are technologies from aerospace or other industries which are fairly mature and could help further define the optimization scheme proposed.
- Derate or uprate control for availability maximization does not appear to have been previously captured based on a brief analysis of the prior art. However, this would require more examination since there are 28 known patent filings on this type of turbine control technology.

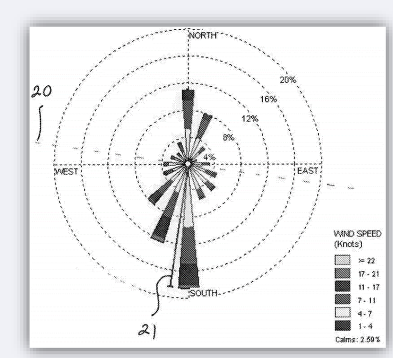
Turbine / wind farm control for electricity price optimization

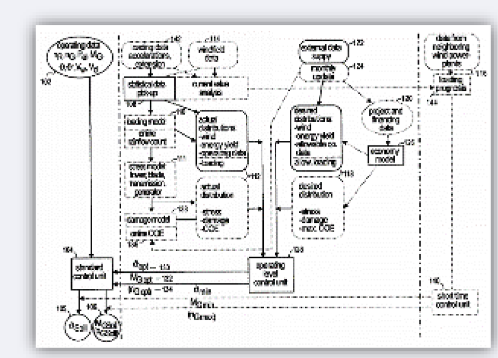
- More in-depth description regarding 10 minute average data to determine optimal power production based on current set price. Uprate (or avoidance of derating) in anticipation of peak power pricing and derating / curtailing during off-peak power pricing to preserve turbine component health should be further explored.
- Maintenance scheduling of a wind farm based on lost income projections for turbine down-time.
- Spare-parts inventory management based on damage accumulation measurements, remaining useful life prediction and/or predicted maintenance interval.
- Integration of this control system with local energy storage for time shifting of price optimization should be further contemplated.
- Power retrieval / balance from energy storage systems to support periods of turbine under-performance. This would involve turbine derating for component life preservation combined with energy storage capability which would allow power output to stay above a threshold level.
- Long term wind farm price and energy output optimization.

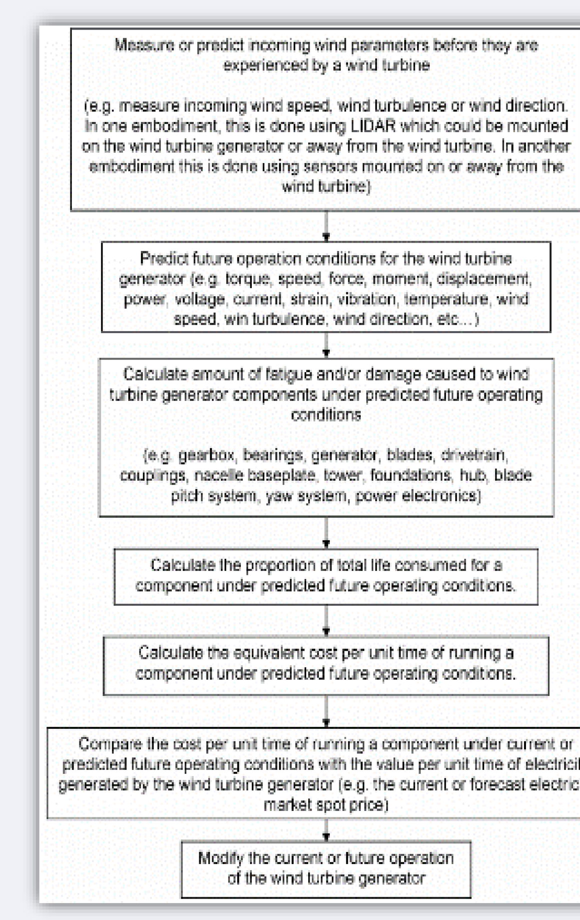
Methods

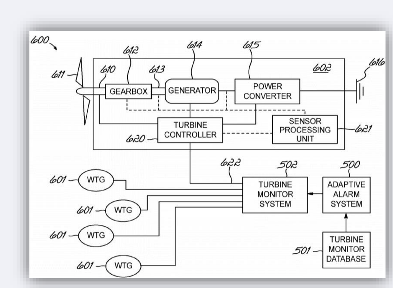
This can be achieved by taking advantage of several key technologies which are already deployed in the wind industry. Here, we present a complete synopsis of a system architecture for an energy optimization system inclusive of the current state of the art technologies based on a scan of the IP landscape as well as other public domain information. In order to be commercially competitive, this system should comprise the following technology:

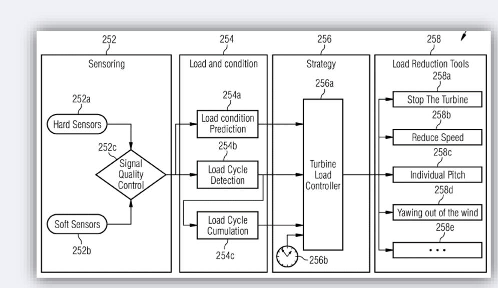
1. Component damage accumulation monitoring including "real-time" stress accumulation monitoring of critical drivetrain, blade and electrical systems components. In this case, stress can be vibratory wear or thermal cycle induced, and can be assessed through SCADA and condition monitoring system data processing techniques and/or the application of additional sensors.
2. Using damage accumulation data fed into models of the turbine control and wind farm control system to predict:
   a. Component life consumption – the percentage of the effective lifetime of a component consumed to date based on wear rate / cumulative damage.
   b. Component life consumption rate – the rate of change of the percentage of the effective lifetime of a component based on the manner in which the system, of which the component is a part, is operated.
   c. Remaining useful component life – predicted failure time-frame based on component life consumption and component life consumption rate. Damage accumulation data must be processed and input into component life estimation models which will take into account:
      i. Monitored component data,
      ii. Software simulations,
      iii. Historical data analysis,
      iv. Wind farm site conditions, and
      v. Neighboring turbine data











wireless data transmission technologies

remotely monitored sensor systems

remote controlled aerial vehicles

Remote inspection technologies

calculating component damage accumulation

calculating remaining useful component / system life

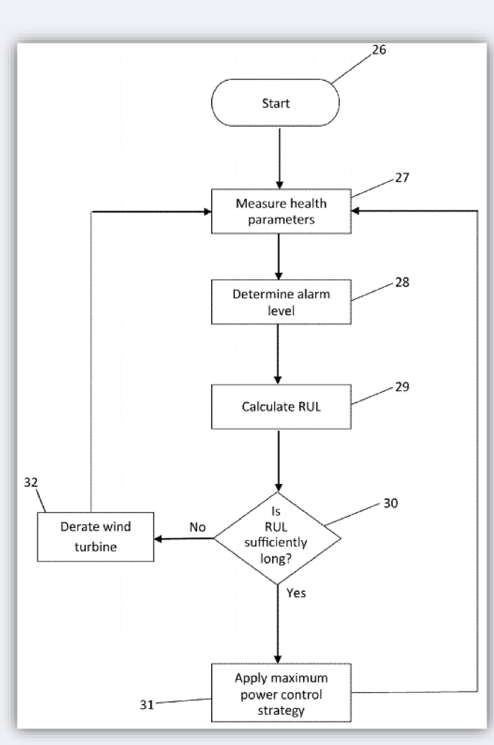
tower climbing inspection 'robots'

optical / video camera based blade tower inspection

Condition based maintenance solutions (CBMS)

turbine output optimization based on remaining useful life

spares demand scheduling



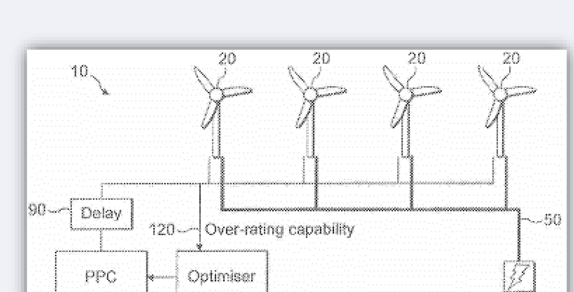


FIG. 5

predictive maintenance scheduling

trend analysis of SCADA data

3. An 'early warning' notification system to wind farm operators about component damage accumulation, component life consumption and remaining useful life. Additional suggestions for energy price optimization, O&M strategy, spare parts sourcing and maintenance scheduling will be incorporated into the system.
4. Energy output optimization:
   a. Uprate for AEP increase when remaining useful component life would not cause un-scheduled maintenance / downtime.
   b. Uprate at times of peak utility price to increase to maximize electricity price.
   c. Regulation of duration and level of turbine uprate to ensure component life consumption or component life consumption rate are below threshold levels (or average levels).
5. Turbine life / component life preservation
   a. Derate for component life preservation in order to prevent un-scheduled maintenance / downtime.
   b. Avoidance of derating at times of peak utility price to maximize electricity price.
   c. Component stress reduction with AEP loss minimized.
6. O&M strategy / maintenance scheduling – avoid sustained turbine operations that result in un-scheduled turbine maintenance. These periods of un-scheduled maintenance result in unavailability of the turbines and will reduce overall wind farm profitability.