DIFFERENT CONTROL METHODS DESIGN FOR WIND TURBE IN HYBRID PHOTOVOLTAIC-WIND SYSTEM

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Abstract - Nonrenewable energy sources are finite; they will be not able to cover the increasing consumption of energy. Their disadvantages also include their high cost and pollution of the environment. Renewable energy sources are the optimal solution for the increasing energy consumption. Photovoltaic (PV) and wind are the most effective sources. A photovoltaic - wind hybrid system will overcome all these difficulties. Wind solar systems are reliable in nature and average cost with clean energy. Control system design is a fundamental part in power systems to maximize energy production. In this study, first, a hybrid wind-photovoltaic system was designed. Then, we focused on designing different controllers for variable speed wind turbine. PID, LQR and H-infinity were applied using state space model.

Keywords - Renewable Energy Sources, Photovoltaic, Variable Speed Wind Turbine, PID, LQR, H-infinity Control.

I. INTRODUCTION

Contrary to traditional energy sources, the energy sources used in renewable energy-based systems are abundant, predictable, and clean in nature. Due to the fact that these renewable energy sources produce less pollution, environmental deterioration, or global warming, they are widely employed. They are crucial in supplying the rising need for clean power. The high initial capital cost is a significant barrier to the utilization of cold-blooded energy systems. PV and the wind system make up the whole hybrid system. The ambient temperature and solar irradiation have a significant impact on the affair power of a solar- PV cell [1].

Additionally, a PV cell can only operate at its highest power output under specific environmental conditions [2]. Because PV units rely on solar energy, they cannot be adjusted or expanded by the driver like conventional generators can. Conversely, synchronous generators can somewhat regulate their affair power by employing governor and excitement systems. This restriction is unimportant in a plant with low penetration levels for PV units, and PV units have little to no impact on the system's dynamics. On the other side, in systems with high PV module penetration, this might result in some very significant issues. PV power plants may be located close to the load centers since they don't have the same environmental issues as traditional synchronous generators. This lowers the system's losses and installation and maintenance costs [1].

The wind energy system consists of an AC-DC converter, generator, gearbox, and wind turbine. Wind energy is transferred by the wind turbine into rotational mechanical energy at turbine shaft, which is then transformed into electrical energy by a generator. A maximum power point tracing MPPT system is utilized to get the most power possible from the wind system [3]. Hybrid generating systems that employ several power sources can significantly increase the constancy of load needs [3]. In fact, hybrid systems can acquire advanced producing capacity. The use of wind energy has increased significantly over the past several decades, and it is today among the most competitive types of renewable energy. The efficacy and dependability of wind turbines, which are big, complex, and fiercely flexible constructions that operate in tumultuous and changing climatic circumstances, depends greatly on a carefully thought-out control approach. A vertical variable-speed wind turbine that operates in the below-rated speed governance is the most common form of wind turbine in which the rotor rotates at different speeds [3].

From a control perspective, the importance is not just on ensuring that the wind turbines are operating at their best, but also working on load reduction and improving grid integration. To do this, wind energy conversion devices must be capable of producing high-quality energy from the wind, a fundamentally unpredictable main source. Different elements of wind energy utilization depend on the wind energy source's characteristics. The amount of energy in the wind fluctuates depending on the wind speed cell [4]. Additionally, the wind speed value affects how well the turbine is managed and which working region. There are two major functioning regimes, the first one refers to the operation at low wind speed, where the control purpose is to maximize energy production. The turbine switches to alternate region when the "rated speed" is attained. The wind's rated speed typically ranges between 14 and 18 m/s [4].The control parameters used to reduce the structural load and to keep the affair power around the nominal value determined by the designer are the pitch angle and the electromagnetic torque.

Related studies concerning the control objective of wind-turbine: On Vancouver Island, Canada, a grid-connected wind farm, [5] employed the linear quadratic regulator (LQR) with MIMO (Multi Input Multi Output) systems to control the voltage for wind farm connected with the grid. A PID, LQR controller, and a non-linear model predictive controller are developed and compared by [6], showing the advantages of non-linear controller. The trials demonstrate potential benefits of model-based nonlinear control techniques. To develop a control strategy, [7] implements and studies a PID and a LQR control for a 2D airfoil section using a stiff spring/damper model in conjunction with an aerodynamic model, the PID control is preferred to the LQR because of its computational efficiency and simplicity. According to [8], for the worst system perturbations, the standard H regulator may be achieved by coupling a certain state estimator and state feedback.

II. MATERIALS AND PROCEDURES

2.1. Photovoltaicwind-turbine system model

Hybrid PV-wind system was simulated in MATLAB (Fig.1). A solar panel part, DC-DC power converter with an MPPT controller, and SPWM single-phase converter make up the main components of a power PV system (sinusoidal PWM). By assuring maximum power transition while the power is continually changing because of external variables such as temperature and irradiance, the MPPT approach is utilized to maximize the use of PV modules.

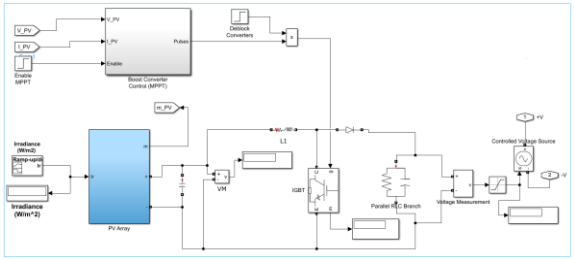


Fig.1 PV model in MATLAB

The model of Permanent Magnet Synchronous Generator (PMSG) based on wind energy conversion system configuration(shown in Fig.2) consist of:

- Wind Energy Conversion
- Wind Turbine
- PMSG
- Inverter

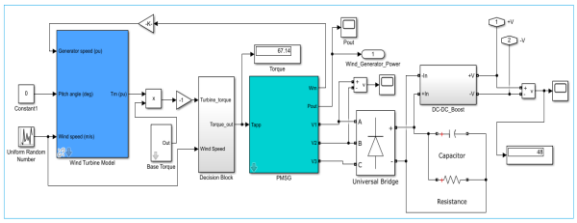


Fig.2 Wind-turbine system model in MATLAB

2.2. Wind-turbine state-space model

The state-space model is used for control objectives. This representation is a way of describing a physical system in terms of variables, its inputs and outputs, which are related by differential equations. Using a drive train model (Fig.3) consisting of a first-order equation of motion represented by either a slow- or fast-moving shaft.

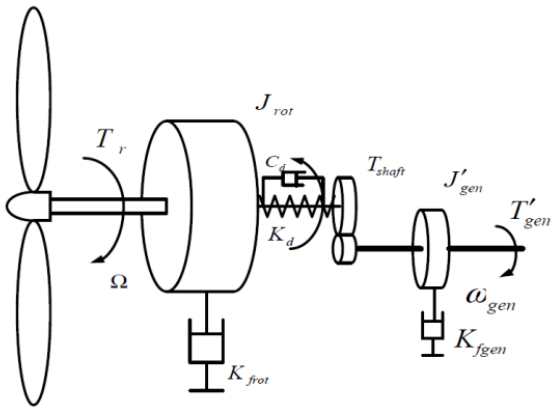


Fig.3 Drive-train model

The aerodynamic torque expression is given by [9].

$$T_r = \frac{1}{2}\frac{\pi\rho R^2 C_P(\beta,\lambda)}{\lambda}v(t)^2$$

The torque coefficient isCp(β,λ). Itchanges with the blade pitch angle β and the speed ratio λaccording to [9, 10]:

$$C_P(\beta,\lambda) = 0.22\,(\frac{116}{\lambda_i} - 0.4\beta - 5)e^{-\frac{22.5}{\lambda_i}}$$

Where, ρ air density, R rotor radius, v(t) wind speed, β pitch angle, λ tip speed ratio, Ω rotor speed.

Based on a nonlinear reduced collective pitch model of a wind turbine, including the shaft dynamics of the drivetrain, the longitudinal motion of the elastic tower, thepitch actuator dynamics, and the generator dynamics, defining state and input vectors:

$$x = (d, \dot{d}, \Omega, \beta_e, \dot{\beta}_e, T_{ele})^T$$
$$u = (\beta_c, T_{ele})^T$$

$$A = \begin{bmatrix} \frac{(\gamma - C_d - K_{frot})}{J_{rot}} & \frac{-1}{J_{rot}} & \frac{C_d}{J_{rot}} \\ K_d & 0 & -K_d \\ \frac{C_d}{J_{gen}} & \frac{1}{J_{gen}} & \frac{-C_d - K_{fgen}}{J_{gen}} \end{bmatrix}, B = \begin{bmatrix} \frac{\xi}{J_{rot}} & 0 \\ 0 & 0 \\ 0 & \frac{-1}{J_{gen}} \end{bmatrix}, \Gamma = \begin{bmatrix} \frac{\alpha}{J_{rot}} \\ 0 \\ 0 \end{bmatrix}, \quad C = [0 \;\; 0 \;\; 1], \quad D = [0]$$

$$\begin{cases} \dot{x} = Ax + Bu + \Gamma u_D \\ y = Cx + Du \end{cases}$$

Where:

- d tower top fore aft displacement.
- βe effective pitch angle.
- T_{ele} effective electrical reaction torque.
  - Kd elastic constant of propeller shaft.
  - Cd damping constant on propeller shaft.
  - J_{rot}, J_{gen} rotation inertia of low-speed side and generator.
  - K_{fgen}, K_{frot} friction constants of high-speed side and low speed side respectively.
    ξ the damping factor.
  - λ is the corrected TSR, which is related to the apparent wind during the tower fore-aft motion.
  - $\alpha = \partial T_r / \partial V |_{(V_0,\Omega_0,\beta_0)}$

2.3. Controllers design

Using the model with parameters values [8], the following controllers were designed.

PID Controller

The PID controller is regarded as the most flexible controller because of its simplicity, linear functioning, and ease of application in control systems [9].

The nonlinear dynamic parameters of the wind turbine system are linearized at their own operating point while developing this controller in order to get the optimal values of (Vωo, βop, ωrop). Fig.4shows the block diagram of the wind turbine system's blade angle control using this linearized model and PID controller.

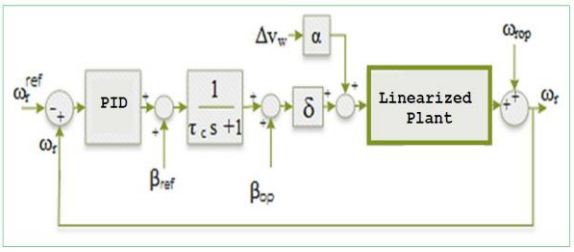


Fig.4 PID control using linearized model

Gain scheduling, a technique that is proposed to account for variations in the sensitivity of the aerodynamic torque to the pitch angle, is used to improve the performance of the PID controller in wind turbines [8].

H-infinity

The H principle seeks to minimize the impact of noises and disturbances occurring on the system without assuming anything about them.

Fig.5 illustrates the closed loop system of the classic H control issue using the preceding state model.

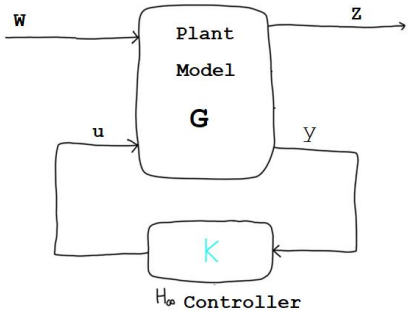


Fig.5 H-Infinity control problem diagram

Where:

$$G = \begin{bmatrix} A & B_1 & B_2 \\ C_1 & D_{11} & D_{12} \\ C_2 & D_{21} & D_{22} \end{bmatrix}$$

The generalized linear time-invariant system G is defined by the equation below. Design of the $H\infty$ controller [8], where the controller signal is u(t), while the state variables are x(t), controlled outputs are z(t), measured outputs are y(t), disturbance signals are$\omega(t)$.

$$\dot{x}(t) = Ax(t) + B_1\omega(t) + B_2u(t)$$
$$z(t) = Cx(t) + D_1\omega(t) + D_2u(t)$$
$$y(t) = x(t)$$

The closed –loop state space model from $\omega(t)$to $z(t)$ becomes as:

$$\dot{x}(t) = A_{cl}x(t) + B_{cl}\omega(t)$$
$$z(t) = C_{cl}x(t) + D_{cl}\omega(t)$$

A static feedback controller with the formula:

u(t) = Kx(t)

exists if the symmetric positive Q and the matrix R isexisted. This controller stabilizes our system.
K = RQ-1 yields the best H controller as a result.
Convexity is achieved by changing W=KX to produce the following inequality:

$$\begin{bmatrix} AX + XA^T + B_2W + W^TB_2^T & B_1 & xC_1^T + W^TD_{12}^T \\ B_1^T & -\gamma I & D_{11}^T \\ C_1X + D_{12}W & D_{11} & -\gamma I \end{bmatrix} < 0$$

LQR Control

The regulation problem at the trim point may be characterized as follows using the prior state-space model for wind-turbine system pitch control and a linear quadratic regulator (LQR) as state feedback:

$$J = \frac{1}{2}\int_0^\infty (\Delta y^T Q \Delta y + \Delta u^T R \Delta u)\, dt$$

Where, $Q \geq 0$ and $R > 0$ are symmetric weights matrices that may be planned using the mean wind V, i.e., Q = Q(V), and R = R(V).
Determination weights for a particular goal-oriented performance is described in [11].
The feedback control that reduces the cost value is provided by:

$$P_c . A + A^T . P_c - P_c . B . R^{-1} . B^T . P_c + Q = 0$$

According to the Bryson's rule, which specifies that it contains matrices so that all diagonals with non-zero components are scaled and the variables in the optimization criterion have a maximum value of 1, the weighting matrices R and Q are chosen. Additionally, the state vectors and units change numerically depending on the various command components, such as pitch angle and electromagnetic torque. R and Q values are selected to provide the system very good performance.

III. RESULTS AND DISCUSSION

The average wind speed of 16 m/s serves as the operational point in the simulation for the system's linearization. The simulation result for PID regulation, KP 6, KI 1.5, is displayed in Fig.6.

For LQR, choosing R = 1, $Q = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 10^{-11} & 0 \\ 0 & 0 & 40 \end{bmatrix}$

From matrix A, B, Q and R, state feedback matrix:

$$K = [2.2 \;\; 10^{-7} \;\; -1.2]$$

H∞ was calculated in MATLAB using Linear Matrix Inequality LMIoptimizer(Yalmip and Sedumi).

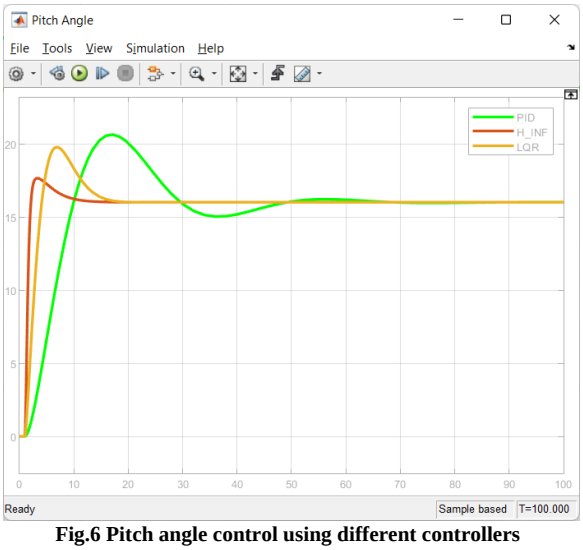


Fig.6 Pitch angle control using different controllers

Where the H-infinity algorithm has a considerably smaller overshoot and time response than the PID, which can reduce the action of the pitch actuator. LQR has a faster response than PID, but its overshoot is large in comparison to H-infinity.

IV. CONCLUSION

Hybrid PV-wind system was modeled. Our contribution is applying three different control methods for wind-turbine pitch control using state space model obtained from [8]. PID control is simple, highly effective, and it is easily tunable. However, it does not work with nonlinear wind turbines and performs poorly when the wind speed changes suddenly. Gains in H-infinity may be managed by altering the performance environment. There is no requirement for a short-term estimator of system parameters. However, the effectiveness depends on the linearized turbine model. LQR pitch control method improve the pitch control performance. This technique had strong control performance over the generator rotate speed and could lessen the pitch actuator's movement. The results demonstrated that H-infinity performs well, and it is efficient. Therefore, it has a lot of potential for use in related applications.

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