Control System Design to Increase Low Voltage Ride Through (LVRT) Capacity in Wind Turbine Using STATCOM Base on Control Linear Quadratic Regulator (LQR)

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***Abstract* - Energy production from the wind turbine power is an intermittent energy source, producing a fluctuating amount of electrical energy according to the uncertain wind energy potential, making the risk of disconnecting the power grid very high and wind power plants can be disconnected from the power grid due to excess or lack of production capacity of the wind turbine. This matter can have an impact on the stability of the transmission system in the electricity network. This research aim: to increase the capacity of the LVRT (Low Voltage ride through) in the turbine so that the generator will continue to operate and not be disconnected from the transmission line when the disturbance occurs. In this study the STATCOM (Static synchronous compensator) will be used to regulate voltage by generating or absorbing reactive power, this tool reduces the risk of voltage drop when the reactive power is working. The method used in this research is the LQR (Linear Quadratic Regulator) system for optimal control in linear systems, used to adjust the performance of STATCOM and increase the capacity of the LVRT. The simulation results show that LQR can produce a control system that can measure reactive currents when there is a voltage drop and can achieve steady-state stability when a disturbance occurs.**

Keywords—LVRT (Low Voltage ride through), STATCOM (Static synchronous compensator), LQR (Linear Quadratic Regulator), steady-state stability.

I. INTRODUCTION

Indonesian country is very feasible in developing and producing renewable energy, especially wind energy. The largest wind power plant has been built in the Sidrap area of South Sulawesi. In the wind power generation system, the wind turbine will take advantage of wind speed and convert it into mechanical energy. After that process in the turbine, the generator will convert this energy into electrical energy [1]. When there is a fault across the stator terminals of a wind turbine generator, the electrical torque is reduced, but the mechanical torque is still present as the wind continues to blow. This condition causes the rotor speed to increase, and if the voltage drop continues, the turbine accelerates the rotor and the rotor speed can become unstable [2]. Increased penetration of wind energy in wind turbines has a significant impact on grid stability. Frequency and voltage stability are very important as they relate to system reliability and safety [3]. This is an important aspect in the design and operation of power plants as wind turbines grow in size and must continue to operate without being disconnected from the grid [4].

A large loss of generating capacity in a power plant combined with an increase in wind energy production creates problems for the power generation system [4]. This has a significant impact on grid stability when generators must remain connected to the grid [5]. This interference causes Low Voltage Right Through (LVRT) instability. When a fault occurs at the Stator terminals of a wind turbine generator, the electrical torque is reduced and the mechanical torque is still present because the wind is still blowing [6]. The maximum voltage that a wind turbine can sustain without suffering from rotor speed instability, known as the drive-through capability of low-voltage wind turbines, decreases either in magnitude or time [7]. The wind turbine rotor speed try to achieve stability on the index which requires a certain voltage [8].

LVRTs are required in wind turbine generators when grid disturbances or large load changes cause temporary voltage dips in the grid [9]. To maintain system stability and reduce the risk of brownouts, the required LVRT operation is specified in grid codes issued by grid operators [10]. Each voltage source converter's principal control level has been updated utilizing the LVRT approach without the use of a communication link [11]. The power generation must maintain grid synchronization even in the event of a severe voltage decrease [12]. Since wind turbines have different characteristics than normal power plants [13], the grid code was created taking into account the synchronous generators used in conventional power plants. Voltage and frequency standards comply with applicable regulations and quickly return to normal when the system is disturbed. The simulation modeling carried out is the Sulawesi interconnection system starting with the usual situation of the Sidrap PLTB on the system when a three-phase short circuit occurs, then the entry of STATCOM on the system.

II. MODEL OF THE SYSTEM

A. Generator model

The system model in this study is to make the LVRT capacity in wind power plants even better by using Linear Quadratic Regulator (LQR). The system model will include wind turbines, generators, and STATCOM. Generator modeling uses a two-axis model that accounts for transient effects while ignoring sub-transient effects. Transient effects are related to the rotor circuit. The expression that the rotor motion of a synchronous machine is the product of the rotor moment of inertia times the angular velocity is written in the vibration equation as (1).

$$J\frac{d^2\theta m}{dt^2} = T_a = T_m - T_e \quad N - m \tag{1}$$

The fundamental equation that affects the dynamics of the rotation of the synchronous machine on the stability problem is also called the swing equation of the machine can be written as (2).

$$\frac{2\mathrm{H}}{\omega_s}\frac{\mathrm{d}\omega}{\mathrm{dt}} = \mathrm{P_m} - \mathrm{P_e} \text{ per unit} \tag{2}$$

The change in P_e is primarily determined by the system transmission, distribution, and load conditions when the generator is delivering power. Disturbances in the grid created by load changes or circuit breaker operation can cause rapid changes in generator output during electromechanical transients. The engine has two stator circuits and two rotor circuits, the network generated by load changes or circuit breaker operation can cause the generator output to change rapidly in the presence of electromechanical transients. The differential equations describing this system are simplified because λd and λq are neglected in the stator equation.

$$E + x_d I_d = E_q' + x_d' I_d \tag{3}$$

$$E_d + x_q I_q = E_d' + x_q'' I_q \tag{4}$$

$$\tau_{q_0}' E_d' = -E_d'(x_q - x_q')I_q \tag{5}$$

$$E_q' = \frac{1}{\tau_{d_0}'}(E_{FD} - E) \tag{6}$$

$$T_e = E_d' I_d + E_q' I_q - (L_q' - L_d')I_d I_q \tag{7}$$

$$\tau_j \omega = T_m - D\omega[E_d' I_d + E_q' I_q - (L_q' - L_d')I_d I_q] \tag{8}$$

$$\delta = \omega - 1 \tag{9}$$

$$E = E_d' - (x_d - x_d')I_d + E_\Delta \tag{10}$$

This equation can represent the two-axis generator model in the form of a diagram as follows:

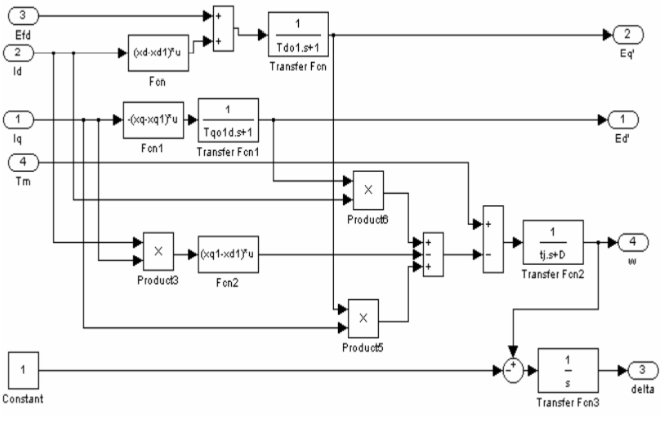


Fig. 1. Two -axis generator model

The magnetic field controls the magnitude of the voltage generated and can be adjusted by changing the current through the magnetic field coils. Increasing the field current increases the resulting voltage and vice versa. The excitation system that controls the generator EMF, output voltage, power factor. Excitation model current can be thought as in Fig. 2.

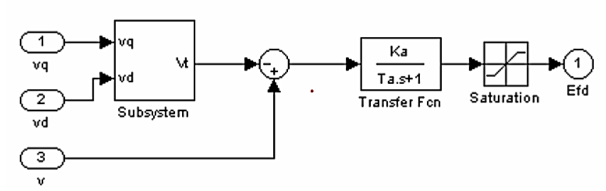


Fig. 2. the excitation model

A system designed to regulate the engine speed on a generator with very high resistance in the event of a load change can be seen in the governor, the governor is a rotor speed controller on the generator which functions to stabilize the mechanical torque value into the generator input.

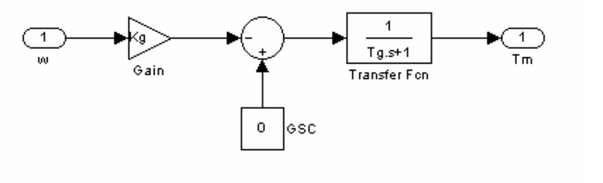


Fig. 3. The governor model

B. The System Model

If the state of the system is asynchronous after a disturbance, efforts should be made to bring the system back into sync. The ultimate goal achieved with this journal is steady-state stability. Steady-state stability is the ability of the power system in the generator to accept disturbances that occur near the equilibrium point under certain conditions. This type of stability depends on the characteristics of the components that make up the power system, such as generators, loads, the grid, and the control of the system itself. The generator model used is a simple generator (constant voltage source) because it only involves disturbance around the equilibrium point. For more details, the system model is made as in Fig. 4.

This system control model is recommended for checking the power performance of systems including generators, wind turbines and STATCOM.

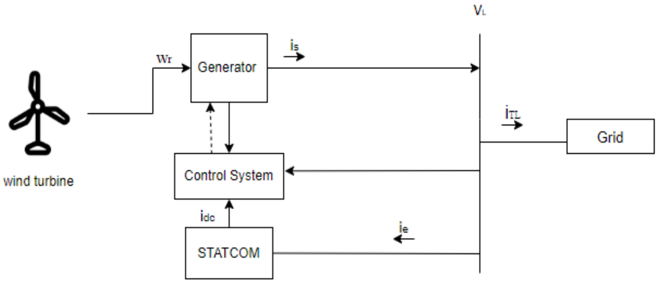


Fig. 4. The system model

C. The STATCOM Model

Reactive power control by the STATCOM is done by comparing the terminal voltage values between the STATCOM and the system. If the STATCOM voltage is low, the STATCOM will absorb the reactive power of the system. If the value is higher than the system, it will generate reactive power in the system. The working principle of STATCOM is shown in (11) – (13).

$$P = \frac{v_s v_c sin\delta}{X_L} \quad (11)$$

$$Q = \frac{v_S(v_S - v_c) sin\delta}{X_L} \quad (12)$$

$$S = 3\frac{v_s v_c}{X_L} sin\delta - j3\left(\frac{v_s v_c}{X_L} cos\delta - \frac{{v_s}^2}{X_L}\right) = P - jQ \quad (13)$$

Power system stability can generally be defined as the ability of a power system to remain synchronized during and after a fault. This definition also applies to systems that operate by interconnecting multiple generators (multi machine). The dynamic behavior of the STATCOM can be written as (14) – (17).

$$i_{de} = \frac{1}{L_f}\left[(v_{ds} - e_d) - R_f i_{de}\right] + \omega_s i_{qe} \quad (14)$$

$$i_{qe} = \frac{1}{L_f}\left[(v_{qs} - e_q) - R_f i_{qe}\right] + \omega_s i_{de} \quad (15)$$

$$v_{dc} = \frac{k}{C}\left(i_{de} cos\alpha + i_{qe} sin\alpha\right) - \frac{v_{dc}}{RC} \quad (16)$$

$$e_d = k v_{dc} \cos\alpha,\ e_q = k v_{dc} sin\alpha \quad (17)$$

III. DESIGN CONTROL SYSTEM

The first step in control system design is linearization, we can say x_0 is the initial state and u_0 can be the appropriate input vector with small signal point balance. If there is a disturbance in the system then:

$$x = x_0 + \Delta u$$
$$= f[(x_0 + \Delta u), (u_0 + \Delta u)] \quad (18)$$

If the disturbance is assumed to be small and the function is nonlinear $f = (x, u)$ can be solved by the Taylor series as (19).

$$x_i = x_{io} + \Delta x_i = f[(x_0 + \Delta u), (u_0 + \Delta u)]$$
$$= f_i = (x_0, u_0) + \frac{\partial f_i}{\partial x_1}\Delta x_1 + \cdots + \frac{\partial f_i}{\partial x_n}\Delta x_n + \frac{\partial f_i}{\partial u_1}\Delta u_1$$
$$+ \cdots + \frac{\partial f_i}{\partial u_r}\Delta u_r \quad (19)$$

Then the linearization of the equation is:

$$\Delta x = A\,\Delta x + B\,\Delta u \quad (20)$$
$$\Delta y = C\,\Delta x + D\,\Delta u \quad (21)$$

After we determine the eigenvalues in the matrix, this value is a scalar quantity with a parameter λ which is solved by (22).

$$A\,\phi = \lambda\phi \quad (22)$$

The eigenvalues determine the stability of the system. To determine the eigenvalues you can use (23).

$$(A - \lambda I)\,\phi = 0 \quad (23)$$

Control system in general can be expressed in (24).

$$x = Ax + Bu \quad (24)$$

Control system design generally chooses a vector u(t) so that the given performance index can be minimized. Then we can get the linear control law relationship. Where K is the matrix r x n

$$u(t) = -Kx(t) \quad (25)$$

Therefore, the design system of the optimal regulator control system based on the quadratic performance index refers to the determination of the K matrix elements, Determination of the optimal control vector u(t) for the system can be written as (26).

$$J = \int_0^\infty (x^t Q x + u^t R u) dt \quad (26)$$

The Q and R matrices determine the relative error and energy cost. In this case, it is assumed that the control vector u(t) does not change. The optimal control system will minimize the performance index and the system will be stable.

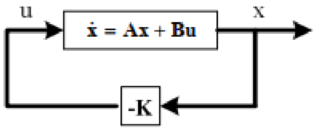


Fig. 5. Optimal control system

By substituting the optimal control equation and vector u(t) we get:

$$x = Ax - BKx = (A - BK)x \quad (27)$$

Then replace the optimal control vector equation u(t) with the vector equation u(t) :

$$J = \int_0^\infty x(Q + K.RK)x dt \quad (28)$$

To see the results of the optimization parameter problem, the following equation is used:

$$x\big((Q + K.RK)x\big) = -\frac{d}{dt}(x\,.px) \quad (29)$$

The next system design is to solve the reduced Riccati matrix equation:

$$A\,.P + PA - PBR^{-1}B\,.P + Q \quad (30)$$

The result of the reduced Riccati matrix is the P matrix after which it is substituted in the equation:

$$u(t) = -Kx(t) = R^{-1}B * Px(t) \quad (31)$$

The result of this equation is the optimal matrix.

IV. SIMULATION RESULT

The performance of control system was evaluated using Matlab/Simulink simulations. First we see the results of the usual situation of the Sidrap PLTB on the system when a three-phase short circuit occurs before installing STATCOM We can see in the Fig. 6 to Fig. 9.

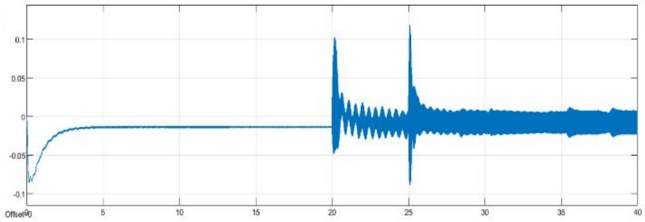


Fig. 6. d-axis Generator

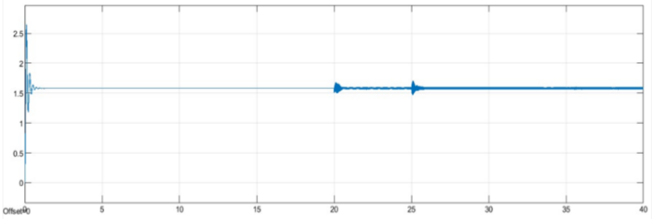


Fig. 7. q-axis Generator

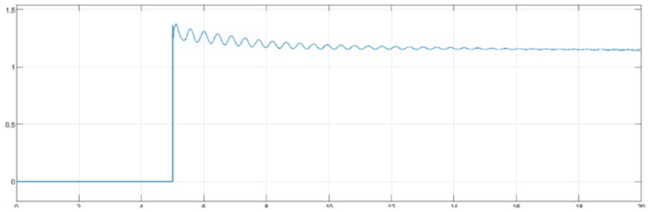


Fig. 8. Stator

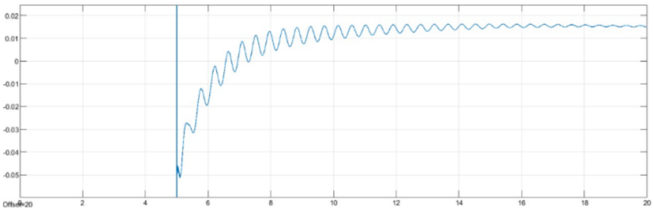


Fig. 9. Rotor

To find out the system can achieve stability or not after installing STATCOM system, it can be seen from the response of the generator on the system. The response of the d-axis and q-axis of the generator can be seen in Fig. 10 and Fig. 11.

We can see that the results of the d-axis and q-axis generators show significant changes to the addition of STATCOM capacity. The response from the stator can be seen in Fig. 12.

To stabilize the generator speed and ease the calculations, the STATCOM and stator current are assumed equal. The response of the rotor can be seen in Fig. 13.

The greater the moment of inertia, the smaller the value of the rotor angle. By reducing the mechanical torque during rotor acceleration, its speed can be decelerated and stabilized more quickly. After knowing the results of the rotor, we can compare the simulation results for static and dynamic generator loads. The response of static load can be seen in Fig. 14.

In the simulation, it can be seen that the static load on the Sidrap PLTB generator overshoots at 5 seconds and oscillates slightly until it finally reaches its steady state value. The response of dynamic load can be seen in Fig. 15.

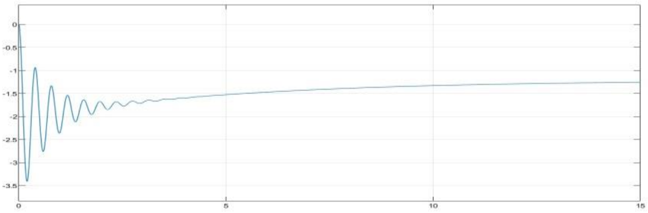


Fig. 10. d-axis Generator

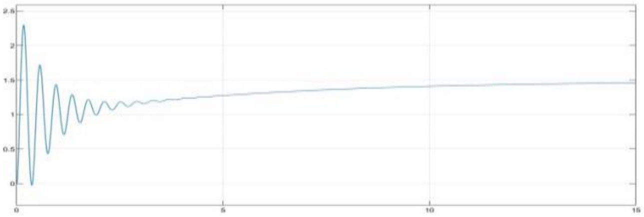


Fig. 11. q-axis Generator

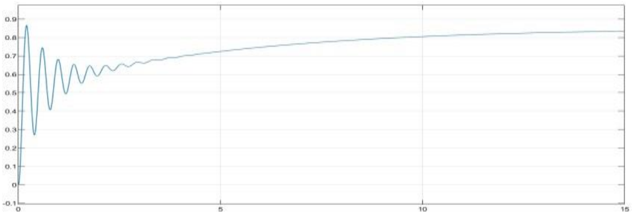
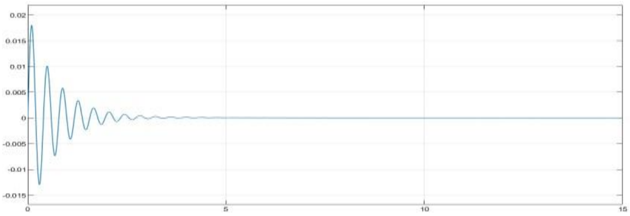


Fig. 12. Stator



Fig, 13. Rotor

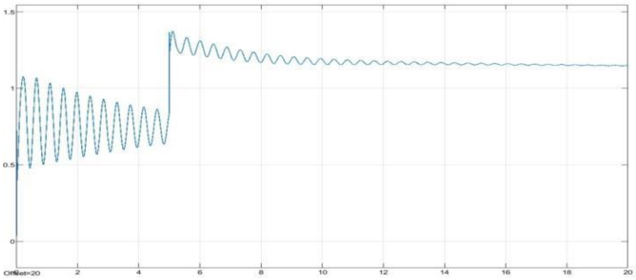


Fig. 14 Static Load Generator

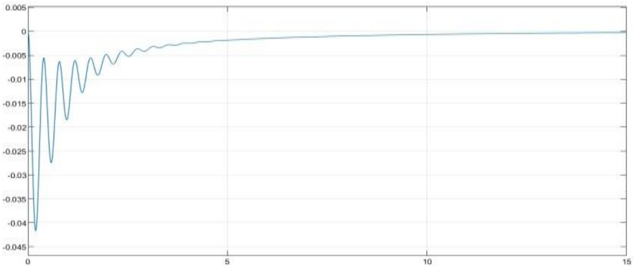


Fig. 15. Dynamic Load Generator

With the simulation results from dynamic loads, the results show that the system is getting better with smaller oscillations and a faster peak response and there is no overshoot before getting steady state stability. From the simulation results after linearization, the optimal Eigen value is obtained as followed:

E = 1.0e + 04
-0.0634 + 0.000i
-6.6663 + 0.0377i
-6.6663 - 0.0377i

The result of the reduced Riccati matrix we can get the optimal gain matrix k as followed:

K = 1.0e + 04

-1.0006	0.0029	0.3242
0.0029	-1.0079	-0.9313

V. CONCLUSION

The simulation results by adding a control system, the LVRT capacity has increased and quickly makes the STATCOM control better, it can be seen from the response of the generator with a dynamic load having a higher peak response and a longer stability time compared to a generator with a static load. Using the LQR system makes the generator response oscillations to dynamic and static loads more damped and achieve steady state stability faster and the STATCOM response value will be close to the recommended value of 1 pu.

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