Application of Novel Adaptive Control of STATCOM in Wind Power Generation

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Abstract: - During the last years the amount of installed wind power has continued increased. The impact of wind generation on the electrical system should be assessed to figure out potential hazards to system operation and decreasing of quality, stability and reliability of power system. Recently the FACTS devices have been used for flexible power flow control, secure loading, damping of power system oscillations and even for the stabilization of wind energy generation. In the paper is suggested novel control of STATCOM on the basis of astatic adaptive singular regulator. The adaptive regulator is identify in real time on the basis of estimated parameters and variables of identification model and after that is create a controlling signal for STATCOM. The operation of wind farm with electric grid connected through transmission and STATCOM is being investigated. Thanks to this adaptive control the power system damping is largely increased, like all transient processes performances are improved.

Key-Words: - Wind generation, Induction generator, FACT device, STATCOM, SVC, Adaptive control

1 Introduction

In the recent years the wind power became one of the most important renewable energy technologies. The installation of wind power generation connected to the grid has increased notably. The advantages are clear, but wind power generation has some drawbacks that must be taken in account.

Most used are squirrel-cage induction generators (IG) because of their simple and maintenance free construction. The IG has many advantages over the synchronous generator: brushless (squirrel cage rotor), reduced size, rugged and low cost. But the, induction generator offers poor voltage regulation and its value depends on the prime mover speed, capacitor bank and load. Also it has some stability problems, it is necessary to investigate the stability aspect of induction generator when connected to the power grid [1]. In the induction generator, the amount of power converted depends on the magnitude of the grid voltage at the connection point with the grid. When a fault occurs somewhere in the grid, which causes a voltage drop at the connection point, the induction generator speeds up due to the unbalance between the mechanical shaft torque and the generator’s electromagnetic torque. During this time, the induction generator draws more reactive power from the grid and contributes further to the connection point voltage collapse [2].

Under these conditions, the power systems must to resolve some major operating problems as voltage regulation, power flow control, transient stability, damping of power oscillations and etc.

Flexible AC transmission system (FACTS) devices [3] can be a one solution to these problems. They are able to provide fast active and reactive power compensations to power systems, and therefore can be used to provide voltage support and power flow. The more efficient utilization of existing transmission networks is obtained when the FACTS devices are suitable located.

The STATCOM is a Voltage Source Converter (VSC) that can generate or absorb both, active or reactive power in a controlled manner. It is a voltage source where amplitude, frequency and phase are completely controllable.

The reactive power exchange is made by varying the amplitude of the voltage in the STATCOM with respect to that of the system. If the amplitude of the voltage in the STATCOM is higher than this in the point of connection, current will flow from the STATCOM to the system, thus, acting like a capacitor injecting reactive power [4].

The active power exchange is similar, and it is done controlling the phase angle of the STATCOM with respect to that of the system. If they have the same angle, there is not active power exchange.

For control of FACTS devices is using all known methods from the theory of automatic control: classical PI-regulators, methods of fuzzy logic and neural network, regulators with adjusted parameters, regulators
with variable structure and others. The main trend is to make these controllers adaptive [5, 6].

However, this is related to the need for large computational resources, which will worsened their performance and hence - the quality of regulation.

The suggested adaptive regulator from us used optimal singular adaptive observers. These observers based on measured parameters of the controlling object identify the parameters and variables of minimal model of Frobenius. The main difference of this identification from the known is that not only the current vector is estimated but and the initial vector. That avoiding from the known is that not only the current vector is estimated but and the initial vector. Thanks to this, the calculation time of the control signal and feedback is negligible small in comparison with the speed of running processes in the system.

Therefore, these regulators improve all parameters of the transition process, damping the oscillations and improving power system stability like whole.

2 Studied power system

In the report is studied power system Fig.1, including wind farm connected to electric grid by transmission line and static compensator (STATCOM). A wind farm consisting of six 1,5 MW wind turbines is connected to a 25-kV distribution system exports power to a 120-kV grid through a 25-km 25 kV feeder. The 9 MW wind farm is simulated by three pairs of 1,5 MW wind turbines. Wind turbines use squirrel-cage induction generators (IG). The stator winding is connected through coupling transformer $T_{r1}$ directly to the electric grid and the rotor is driven by a variable-pitch wind turbine. The pitch angle is controlled in order to limit the generator output power at its nominal value for winds exceeding the nominal speed (9 m/s). In order to generate power the IG speed must be slightly above the synchronous speed.

Fig.1. Diagram of studied power system

Reactive power absorbed by the IGs is partly compensated by capacitor banks connected at each wind turbine low voltage bus (400 kVar for each pair of 1,5 MW turbine). The rest of reactive power required to maintain the 25-kV voltage at bus $B$ close to 1 p.u. is provided by a 3-MVar STATCOM.

![Fig.2. Block diagram of STATCOM control](image)

The power circuit of the STATCOM consists of a three-phase voltage source converter and a coupling transformer $T_r$. Here, a cascaded control structure in rotating coordinates aligned to the grid voltage angle is used as described in [7] and [8]. The structure of the STATCOM control is shown in Fig.2. The grid voltage $U_g$ and the shunt current $I_p$ are measured. The inner current control loop forces the voltage source converter to behave as a controlled current source. A power transformer is presented to connect the STATCOM to the electric grid. The grid voltage is controlled by an adaptive controller and gives the reference signal for the $q$-current controller. To regulate the DC voltage of the outer control loop to its constant value a PI controller is used. To design the PI controller parameters, the inner control loop is modeled as a first order delay element and the dynamics of the DC link are taken into account. The controller is tuned with the symmetrical optimum [9]. The inner current control is performed in rotating $dq$-coordinates with PI controllers as well. Grid synchronization is done with a PLL algorithm.

3 Algorithm for adaptive control for STATCOM

The basic idea for the STATCOM control is keeping the voltage magnitude close to the reference point, which is given from the operator. The adaptive regulator creates control signal $I_{dref}$ which identified control object by optimal singular adaptive observer (OSAO). The obtained signal after adaptive regulator $I_{dref}$ is feed on the input on the current regulator together with the control signal $I_{dref}$. After that the current regulator creates firing signal for PWM control.

The observed system might be present by a following type of a linear model in the state space describing from following differential equations [10]:

\[
\begin{align*}
\dot{x} &= Ax + Bu + d(t) \\
\mathbf{y} &= Cx + d_w(t)
\end{align*}
\]
\[ x(k + 1) = A x(k) + b v(k), \quad (1) \]
\[ y(k) = c^T x(k), \quad (2) \]
\[ v(k) = u(k) + z(k), \quad (3) \]
where: \( x(k), x(k+1) \) are an unknown current state vector in two neighbor moments of sample; \( x(0) \) is an unknown initial state vector; \( u(k) \) is an input signal; \( z(k) \) is a limited input sequence for identification.

The investigation [11] shows that for STATCOM control regulator could be used minimal models from 3rd order, which ensures high rapidity and sufficient accuracy. \( A, b \) and \( c \) are unknown matrices and vectors of the following type:
\[ A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ a_1 & a_2 & a_3 \end{bmatrix}; \quad b = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix}; \quad c = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}, \quad (3) \]

The input/output data are shaped in following matrices and vectors.
\[ Y_1 = \begin{bmatrix} y(0) \\ y(1) \\ y(2) \end{bmatrix}; \quad Y_2 = \begin{bmatrix} y(3) \\ y(4) \\ y(5) \end{bmatrix}; \quad Y_3 = \begin{bmatrix} y(6) \\ y(7) \end{bmatrix}; \quad (4) \]
\[ A = \begin{bmatrix} u(0) & 0 \\ u(1) & u(0) \end{bmatrix}; \quad U_{11} = \begin{bmatrix} u(2) & u(1) & u(0) \\ u(3) & u(2) & u(1) \\ u(4) & u(3) & u(2) \end{bmatrix}, \quad (5) \]
\[ U_{21} = \begin{bmatrix} u(5) & u(4) & u(3) \\ u(6) & u(5) & u(4) \\ u(7) & u(6) & u(5) \end{bmatrix}; \quad Y_{12} = \begin{bmatrix} y(0) & y(1) & y(2) \\ y(1) & y(2) & y(3) \\ y(2) & y(3) & y(4) \end{bmatrix}, \quad (6) \]
\[ Y_{22} = \begin{bmatrix} y(3) & y(4) & y(5) \\ y(4) & y(5) & y(6) \\ y(5) & y(6) & y(7) \end{bmatrix}, \quad (7) \]

The vectors estimate \( \hat{h} u \hat{a} \) is calculating by following expression:
\[ \begin{bmatrix} \hat{h} \\ \vdots \\ \hat{a} \end{bmatrix} = \begin{bmatrix} K^{-1} & \vdots & -K^{-1} Y_1 \end{bmatrix} \begin{bmatrix} Y_2 \\ \vdots \\ Y_3 \end{bmatrix}, \quad (5) \]
where: \( K = U_{11} Y_{12} Y_{22} U_{21} \)

After that is creating
\[ A = \begin{bmatrix} \hat{a}_3 & 0 \\ \hat{a}_2 & \hat{a}_3 \end{bmatrix}, \quad (6) \]

Recurrent vector is calculated
\[ \hat{b} = \begin{bmatrix} \hat{b}_2 \\ \hat{b}_3 \end{bmatrix}, \quad (7) \]
with the help of following equation system
\[ \hat{b} = \hat{h} + \Delta \]

The initial steady state subvector \( \hat{x}(0) \)
remains estimation
\[ \begin{bmatrix} x(0) \\ x(0) \end{bmatrix} = \begin{bmatrix} x_2(0) \\ x_3(0) \end{bmatrix} ] \]

is calculated by optimal subestimator from following type:
\[ \hat{x}(0) = Y_1 - \hat{U} \hat{b} \]

However:
\[ \hat{x}(0) = y(0) \]

The current state vector is estimated by degenerative optimal singular adaptive (OSA) observer:
\[ \hat{x}(k + 1) = A \hat{x}(k) + b u(k), \hat{x}(0) = x_0 \]

The regulating signal \( I_{q\text{ref}} \) is calculated by using of astatic modal state regulator with scale factor \( k_0 \) from following type:
\[ k_0(k) = \begin{bmatrix} k_1(k) & k_2(k) & \ldots & k_n(k) \end{bmatrix} \]
\[ \hat{A}_z = \hat{A} - \hat{b}(k - l) \]
\[ k_0(k) = \begin{bmatrix} e^T (I_n - \hat{A}_z)^{-1} \hat{b}(k - l) \end{bmatrix} \]
\[ I_{q\text{ref}}(k) = k_0(k) y_{\text{ref}} + k(k) \hat{x}(k - l) \]

where: \( y_{\text{ref}} \) is reference signal given from the operator.

4 Experimental results

Simulation studies are carried out in this section to investigate the effect of adaptive control of STATCOM device on power system included wind farm. The test system is exposed to various transient disturbances and the system responses, reinforced with STATCOM device, are compared with the original system. Also is investigating the adaptive control of STATCOM which is compared with conventional PI control. The performed numerous investigations proof rightness of the adaptive control. The present results show the transient processes at varying of wind speed and voltage drop from grid side.

On Fig.3 is shown the part of system parameters at variation of wind speed. Wind speed is increasing from 8 m/s to 11m/s at time 10 sec for couple of IG, 11sec – second couple and 12sec – third couple. In the first three diagrams is shown and compared the adaptive control (with solid line) and conventional PI control (with dotted line) of following parameters: \( U_{b} \) – voltage on bus B; \( Q_{STACOM} \) – generated reactive power of STATCOM; \( Q_{b} \) – reactive power on bus B. On the next two diagrams is shown active power of IG and pitch control angle for wind turbine blades.
On Fig. 4 is shown bus voltage at operating of STATCOM with adaptive control (solid line) and PI control (dotted line) and without STATCOM (bright dotted line). From this figure it is possible to observe the improvement of working conditions throughout the whole system in various disturbances using system device - STATCOM.

5 Conclusions
The wide use of wind turbines in power systems put a large number of problems with their management. Main problem which is deciding, it is providing the necessary reactive power for their excitation. The variation of wind speed and hence the speed of wind turbines implies and control of reactive power.

In the article is suggested adaptive control of STATCOM, which solves the problems of control of reactive power and improve power system quality at various disturbing influences. The proposed adaptive regulator is based on the identification of variables and parameters of the managed object (static synchronous compensator).

Thanks to use of an original observer, identification and calculation of the control signal is carried out in a very short time, much less than the speed of running processes in the system. Thereby is improved very much as quality of regulation and all parameters of the transition process.

References:
[1] Claudio L. Souza et. al., “Power System Transient Stability Analysis including Synchronous and


