Preprints of the 3rd IEEE conference on Energy Internet and Energy System Integration November 8-10, 2019. Changsha, China

Modeling and Simulation of Hydrogeneration System with Doubly Fed Generator

Baiyang Liu*
Shaoyang University
Hunan Provincial Key Laboratory of Grids Operation and Control on Multi-Power Sources Area
Shaoyang, China
liubaiyang2016@163.com

Xiangjun Zeng
School of Electrical & Information Engineering
Changsha University of Science and Technology
Changsha, China
eexjzeng@qq.com

Xiangchun Xiao
Huaihua Design Institute of Water Conservancy and Electric Power
Huaihua, China
2696222506@qq.com

Dongqi Liu
School of Electrical & Information Engineering
Changsha University of Science and Technology
Changsha, China
liudongqi@csust.edu.cn

Li Li
School of Electrical & Information Engineering
Changsha University of Science and Technology
Changsha, China
975940529@qq.com

Xiaoping Chen
School of Electrical & Information Engineering
Changsha University of Science and Technology
Changsha, China
xpchen6538@163.com

***Abstract*—With growing concerns about renewable energy consumption, pumped storage power plant is becoming a popular concept and thus the modeling of the doubly fed generator based hydrogeneration system becomes an interesting research topic. In this paper the power control strategy on the doubly fed generator based on pumped storage power plant with the aim of active power and slip control was studied. Multi-index control was employed to achieve the independent control of active power and slip of the machine. The machine was modeled in state equations in a synchronous reference frame. The complete simulation model was developed for such hydrogeneration system under variable speed operation using MATLAB & Simulink environment for obtaining the optimal parameters of multi-index control and the dynamic performance got further improved.**

***Index Terms*—hydrogeneration system, doubly fed generator, alternating current excitation generator, excitation control, pumped storage power plant**

I. Introduction

Hydropower is one of the main forms of power generation in China, which has the characteristics of clean production and rapid regulation [1]– [3]. With the development of renewable energy generation, high permeability of new energy generation has brought serious problems of power delivery and grid operation, pumped storage power station, as a special kind of hydropower being ability of energy storage, is an effective means to improve the operation performance of renewable energy generation and thus it has been widely concerned [4]– [6]. Under certain conditions such as large changes in head and high silt concentration [7] in hydropower or pumped storage power plant in order to achieve the goal of maximum operational efficiency the speed of the turbine is required to be variable. However, it is well known that the rating speed of hydroturbine is determined in the design stage according to the working principle of the synchronous generator.

As the doubly fed generator (DFG) is equipped with alternating excitation system the speed of hydroturbine can be adjusted in order to track the optimal value and ensure that the machine operates in maximum efficiency. So its application has a broad prospect [8]– [12]. The control system is one of the important component of DFG, which determines its operation performance and has been widely and deeply studied [13]– [18]. The simulation and modeling of hydrogeneration system is the basis and key of research. According to the actual problems and specific research content, the common forms of simulation model include state equations, modules provided by power system simulation software and steady-state equations.

In this paper, the power control strategy on the doubly fed generator based on pumped storage power plant with the aim of active power and slip control was studied. Multi-index control was employed to achieve the independent control of active power and slip of the machine. The machine was modeled in state equations in a synchronous reference frame. The complete simulation model was developed for such hydrogeneration system under variable speed operation using MATLAB&Simulink environment for obtaining the optimal parameters of multi-index control and the dynamic performance got further improved.

II. Modeling Of Hydrogeneration System With DFG

The hydrogeneration system with DFG is described in Fig. 1, which consists of water turbine, DFG, excitation regulator, water diversion system, hydroturbine speed control system, guide vane adjuster, etc. Among them the hydroturbine speed control system ensures that the speed of

This work was supported in part by the Research Foundation of Education Bureau of Hunan Province, China under Grant 17C1436, and in part by the Shaoyang University Hunan Provincial Key Laboratory of Grids Operation and Control on Multi-Power Sources Area under Grant 2016TP1023

hydroturbine can be adjusted in order to track the optimal value and the machine operates in maximum efficiency. The excitation regulator adjusts both the slip of the machine in real time to follow the change of the speed of hydroturbine and active power as required.

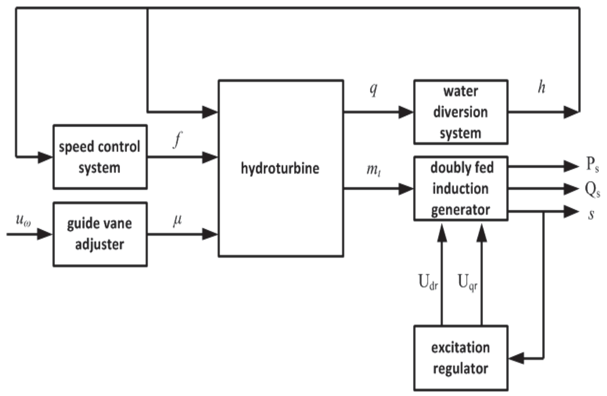

Fig. 1. Basic configuration of hydrogeneration system with DFG.

The general model for hydrogeneration system with DFG is described as follows where the nomenclature has been illustrated in [18].

A. Hydroturbine:

$$\begin{cases} m_t = e_\mu \mu + e_f f + e_h h \\ q = e_{q\mu}\mu + e_{qf} f + e_{qh} h \end{cases} \tag{1}$$

B. Water diversion system:

$$\frac{h(s)}{q(s)} = -T_\omega s \tag{2}$$

C. Guide vane adjuster:

$$\dot{\mu} = \frac{1}{T_y}(-\mu + U_\omega) \tag{3}$$

D. DFG in d–q reference frame:

$$\begin{bmatrix} u_{sd} \\ 0 \\ u_{rd} \\ u_{rq} \end{bmatrix} = Z \begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix} \tag{4}$$

Where

$$Z = \begin{bmatrix} -R_s - \frac{X_\Sigma}{\omega_1}p & -X_\Sigma & \frac{X_m}{\omega_1}p & X_m \\ X_\Sigma & -R_s - \frac{X_\Sigma}{\omega_1}p & -X_m & \frac{X_m}{\omega_1}p \\ -\frac{X_m}{\omega_1}p & -sX_m & R_r + \frac{X_r}{\omega_1}p & sX_r \\ sX_m & -\frac{X_m}{\omega_1}p & -sX_r & R_r + \frac{X_r}{\omega_1}p \end{bmatrix} \tag{5}$$

Therefore,the sate equations of hydrogeneration system with doubly fed generator in a synchronous reference frame using the small signal error method are expressed as follows:

$$\begin{bmatrix} \Delta\dot{P} \\ \Delta\dot{Q} \\ \Delta\dot{s} \\ \Delta\dot{P}_m \\ \Delta\dot{\mu} \end{bmatrix} = A \begin{bmatrix} \Delta P \\ \Delta Q \\ \Delta s \\ \Delta P_m \\ \Delta\mu \end{bmatrix} + B \begin{bmatrix} \Delta u_{rd} \\ \Delta u_{rq} \\ \Delta u_\omega \end{bmatrix} \tag{6}$$

Where

$$A = \begin{bmatrix} -\frac{1}{T'_f} & -s_0 & -(\frac{1}{X'_s} + Q_0) & 0 & 0 \\ s_0 & -\frac{1}{T'_f} & P_0 & 0 & 0 \\ J_H & 0 & 0 & -J_H & 0 \\ 0 & 0 & 0 & -\frac{2}{T_\omega} & \frac{2}{T_\omega} + \frac{2}{T_y} \\ 0 & 0 & 0 & 0 & -\frac{1}{T_y} \end{bmatrix} \tag{7}$$

$$B = \begin{bmatrix} \frac{1}{X'_a} & 0 & 0 \\ 0 & \frac{1}{X'_a} & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -\frac{2}{T_y} \\ 0 & 0 & \frac{1}{T_y} \end{bmatrix} \tag{8}$$

III. Control Strategy

For the doubly fed generator in transient state desired amount of reactive power flow into the stator which can be controlled by controlling i_{dr} and stator active power can be controlled P via i_{dr}. The rotor circuit of the DFG is accessed via slip rings with this slip varies from stator to rotor and rotor to stator than its operated sub synchronous to super synchronous mode of operation. Rotor is accessed via slip rings with this, slip varies from stator to rotor and rotor to stator then its operated sub synchronous to super synchronous mode of operation which can be controlled by controlling U_ω. The multi-index control strategy is described as follows:

$$\begin{cases} u'_{rd} = u'_{rd0} + k_p\Delta P + k_s\Delta s \\ u'_{rq} = u'_{rq0} + k_q\Delta Q \\ U_\omega = k_{pu}\Delta P + k_{su}\Delta s \end{cases} \tag{9}$$

In order to improve the dynamic performance of hydrogeneration system its state equations are extended and partially represented below:

$$\begin{bmatrix} \dot{IDP} \\ \dot{IDs} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \Delta P \\ \Delta s \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta u_{rd} \\ \Delta u_{rq} \\ \Delta u_\omega \end{bmatrix} \tag{10}$$

Where

$$\begin{cases} IDP = \int_0^t \Delta P\, dt \\ IDs = \int_0^t \Delta s\, dt \end{cases} \tag{11}$$

Then the improved multi-index control equations is expressed as follows:

$$\begin{cases} u'_{rd} = u'_{rd0} + k_p \Delta P + k_s \Delta s + k_{is} IDs + k_{ip} IDP \\ u'_{rq} = u'_{rq0} + k_q \Delta Q \\ U_\omega = k_{pu} \Delta P + k_{su} \Delta s + k_{isu} IDs + k_{ipu} IDP \end{cases} \quad (12)$$

IV. Simulation Results

This section illustrates the simulated results of stator active power and slip increment for a step change in u_{rd} at different values of k_{ip},k_{ipu},k_{is} and k_{isu}. The model was simulated using MATLAB&Simulink platform at the value of parameters given in Table I.

TABLE I
Parameters of hydrogeneration system with DFG

Symbol	*Description*	*Value*	*Unit*
J	rotor inertia	10	p.u.
R_r	rotor resistance	0.0065	p.u.
X_r	total rotor reactance	0.8067	p.u.
X_m	mutual reactance	0.79	p.u.
X_s	total stator reactance	0.81	p.u.
X_ω	total external reactance	0.939	p.u.
T_ω	time constant of rigid water hammer	1	\
T_y	time constant of hydraulic pressure	0.5	\
P_b	normal active power	100	MW

A step change in u_{rd} is given at t=0sec. u_{rd} controls the stator active power. Hence a step change in u_{rd} results in change in stator active power and the response of stator active power increment varies with the k_{ip} value which is shown in Fig. 2. Similarly the response of stator active power and slip increment under other conditions is shown in Fig. 3, 4 and 5.

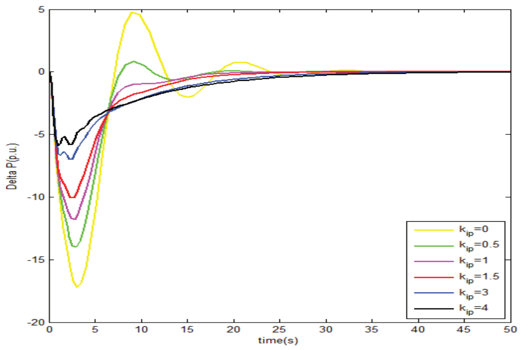

Fig. 2. Change in Delta P with sudden step change in u_{rd} at different k_{ip} values.

It can be seen that multi-index control method can achieve the independent control of active power and slip of the machine. When the value of k_{ip} , k_{ipu} equals roughly 1 and k_{is} , k_{isu} equals roughly 300 the optimal dynamic performance of hydrogeneration system is obtained approximately.

V. Conclusions

In this paper contribution, the state equations of hydrogeneration system in a synchronous reference frame are modeled and extended. The simulation results show that active power and slip of the hydrogeneration system with DFG can be controlled independently and effectively using multi-index control strategy and the optimal parameters of multi-index control can improve its dynamic performance further.

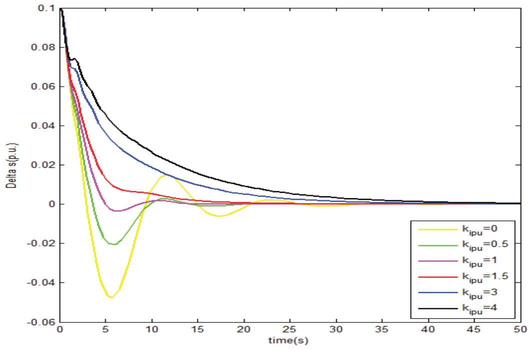

Fig. 3. Change in Delta s with sudden step change in u_{rd} at different k_{ipu} values.

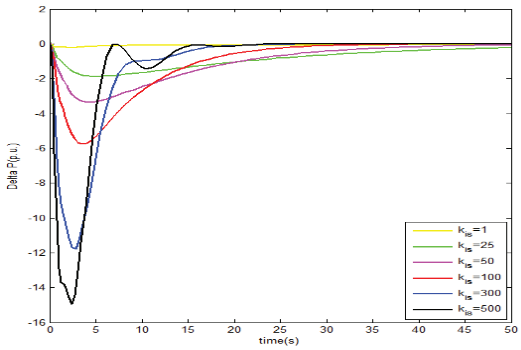

Fig. 4. Change in Delta P with sudden step change in u_{rd} at different k_{is} values.

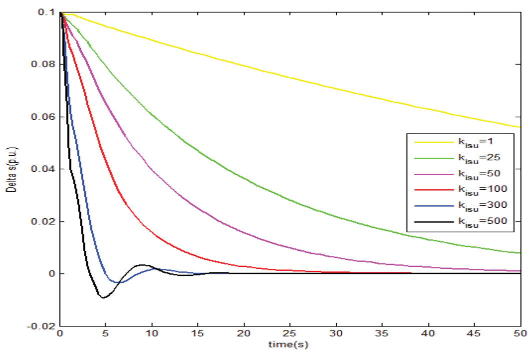

Fig. 5. Change in Delta s with sudden step change in u_{rd} at different k_{isu} values.

Acknowledgment

This work was carried out by Changsha University of Science and Technology, Changsha, China. We gratefully acknowledge the invaluable contribution of Xiangjun ZENG,Dongqi LIU at Changsha University of Science and Technology in preparing this model and simulation.

References

[1] R. Selvaraj, K. Desingu, T. R. Chelliah, D. Khare and C. Bharatiraja, “Fault tolerant operation of parallel–connected 3l–neutral–point clamped back–to–back converters serving to large hydro–generating

units," in IEEE Transactions on Industry Applications, vol. 54, no. 5, pp. 5429–5443, Sept.–Oct. 2018.

[2] Y. Takagi, Y. Sato and H. Takeda, "Development of the electromechanical simulator for variable speed hydro–turbine plant," The SICE Annual Conference 2013, Nagoya, Japan, 2013, pp. 2589–2594.

[3] R. R. Semwal, A. Joseph and T. R. Chelliah, "Two–stage protection for multi–channel power electronic converters fed large asynchronous hydro-generating unit," 2018 International Power Electronics Conference (IPEC–Niigata 2018 –ECCE Asia), Niigata, 2018, pp. 1358–1363.

[4] A. Joseph, K. Desingu, R. R. Semwal, T. R. Chelliah and D. Khare, "Dynamic performance of pumping mode of 250 MW variable speed hydro–generating unit subjected to power and control circuit faults," in IEEE Transactions on Energy Conversion, vol. 33, no. 1, pp. 430–441, March 2018.

[5] R. R. Singh and T. R. Chelliah, "Energy saving start-up strategy of pumped storage power plant equipped with doubly–fed asynchronous machine," 2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), Delhi, 2016, pp. 1–6.

[6] N. Aghanoori and M. A. S. Masoum, "Voltage sag compensation in renewable plant using hydro–pump storage," 2015 IEEE PES Asia–Pacific Power and Energy Engineering Conference (APPEEC), Brisbane, QLD, 2015, pp. 1–5.

[7] S. zeb, N. M. Ali, A. Mujeeb and H. Ullah, "Cost efficient Mini hydro plant with low water head whirlpool design methodology for rural areas: (Micro Hydro Whirlpool power plant)," 2019 2nd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET), Sukkur, Pakistan, 2019, pp. 1–7.

[8] V. Azbe and R. Mihalic, "Transient stability of doubly-fed induction machine in parallel to synchronous machine,"2015 IEEE Eindhoven PowerTech, Eindhoven, 2015, pp. 1–6.

[9] P. L?hdefink, A. Dietz and A. M?ckel, "The brushless doubly fed induction machine as generator for small hydro power – machine design and experimental verification," 2017 Twelfth International Conference on Ecological Vehicles and Renewable Energies (EVER), Monte Carlo, 2017, pp. 1–6.

[10] S. Khatua, S. Mishra, S. Pati, A. Choudhury and K. B. Mohanty, "Voltage & frequency stabilisation of a SEIG based micro–hydro system through a DFIG based WECS equipped with BESS," 2018 Technologies for Smart–City Energy Security and Power (ICSESP), Bhubaneswar, 2018, pp. 1–6.

[11] T. Lugand and A. Schwery, "Comparison between the salient–pole synchronous machine and the doubly fed induction machine with regard to electromagnetic parasitic forces and stator vibrations," in IEEE Transactions on Industry Applications, vol. 53, no. 6, pp. 5284–5294, Nov.–Dec. 2017.

[12] M. Valavi and A. Nysveen, "Variable–speed operation of hydropower plants: Past, present, and future," 2016 XXII International Conference on Electrical Machines (ICEM), Lausanne, 2016, pp. 640–646.

[13] LI Hui and YANG Shun–chang, "Study of control strategies for hydrogenerator system with doubly fed generators based on CMAC neural network," in Zhongguo Dianji Gongcheng XuebaoProceedings of the Chinese Society of Electrical Engineering, vol. 24, no. 12, pp. 187–192, December 2004

[14] H. J. Fard, H. R. Najafi and G. Heidari, "Design of discrete predictive direct power control strategy on the doubly-fed induction generator based on Micro-Hydro Power Plant with the aim of active and reactive powers control,"2016 21st Conference on Electrical Power Distribution Networks Conference (EPDC), Karaj, 2016, pp. 118–124.

[15] S. Mishra, S. K. Gagrai and M. Singh, "An ANN based simulation and control of grid integrated DFIG for 2 MW small hydro power plant," 2019 6th International Conference on Signal Processing and Integrated Networks (SPIN), Noida, India, 2019, pp. 540–546.

[16] A. Paul, G. Joos and I. Kamwa, "Decentralized dynamic state estimation of doubly fed induction generator using terminal measurements," 2018 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), Washington, DC, 2018, pp. 1–5.

[17] W. Hu, P. Zhang, Z. Chen, J. Li, S. Chen and W. Ruan, "Model–based control for doubly fed adjustable–speed pumped storage units with fast power support," 2018 13th IEEE Conference on Industrial Electronics and Applications (ICIEA), Wuhan, 2018, pp. 2227–2232.

[18] LI Hui and YANG Shun–chang, "Stability analysis of control system of adjustable speed hydroelectric generating units with doubly fed generators," in Zhongguo Dianji Gongcheng XuebaoProceedings of the Chinese Society of Electrical Engineering, vol. 24, no. 6, pp. 152–156, June 2004