Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
Make Harmony Between Technology and Nature, and Your Mind will Fly Free as a Bird
Annals of DAAAM International

MODELING AND CONTROL OF THREE-PHASE INVERTER'S RMS OF SWIRL TURBINE BY USING SYSTEM IDENTIFICATION.

HEJC, T[omas]; BREZINA, T[omas] & HUZLIK, R[ostislav]

Abstract: *The increase of distributed production of electric energy from renewable sources has been evident in recent years. An example of such a source is the swirl turbine, developed by the Faculty of Mechanical Engineering in Brno. Construction of the swirl turbine is achieved using a monobloc configuration of the turbine and the generator. Electrical energy from such systems can be controlled with a rectifier and an inverter. This paper deals with the simulated design of a three-phase inverter in the Matlab program. This created model is identified and subsequently is designed a regulation of RMS by method. The resulting identification is important for RMS regulation and for the controllability, stability and quality of the electric energy from such a system.*
Key words: *Swirl water turbine, three-phase inverter, non-linear system identification, control*

1. INTRODUCTION

Potential locations for building hydro-electric power plants with classic turbines (Kaplan, Francis…) are exhausted, especially in Europe. But places with low inclines and high flows are not used on a large scale. These places are ideal for the swirl turbine, developed by the Faculty of Mechanical Engineering in Brno (Haluza et al., 2002), (Pochylý & Haluza 2003). This is a new type of water turbine and it is designed especially for very low inclines (less than 3 meters) and high flows (that means high speed). Construction of this water turbine is based on a monobloc configuration of the turbine and the generator. The supply of electrical energy is provided by the turbine and the generator with the use of a frequency inverter and rectifier.

In recent years, attention was paid mainly to systems that contained solar panels (Ritz-Rivera & Fang, 2004) and wind turbines (Borowy & Salame, 1997). A mathematical description and subsequent phase model (Kroutikova et al., 2007) is important for design of such regulation systems. Because of the analytic method complexity (construction knowledge, parameters knowledge, differential equations and switching typology) experimental approaches are suitable solution for these systems (Nopporn et al., 2010).

This paper deals with the identification of a three-phase inverter. For this reason, this simulation model of a three-phase inverter was created. This simulation model, which was created in the Matlab program, is designed for the swirl turbine. The inverter is composed of power electronics and switch components, which enable non-linear behavior. Modeling and simulation are necessary tools for analysis and operation of such systems (Maksimovic et al., 2001). This non-linear model was identified afterwards which was necessary for the design of robust controlling via method.

The following research will be oriented on a design and controlling of other elements in this system with the main effort focusing on keeping the swirl turbine at the highest efficiency levels. The next task will be the construction of multiple turbines with different diameters of their action wheels.

The aim is to develop a fully automatic system with the highest efficiency for electrical energy production.

2. MODEL OF THREE-PHASE INVERTER

In the Matlab program, the three-phase inverter was designed, see Fig. 1. The three-phase inverter system is very non-linear because of the switching components and diodes.

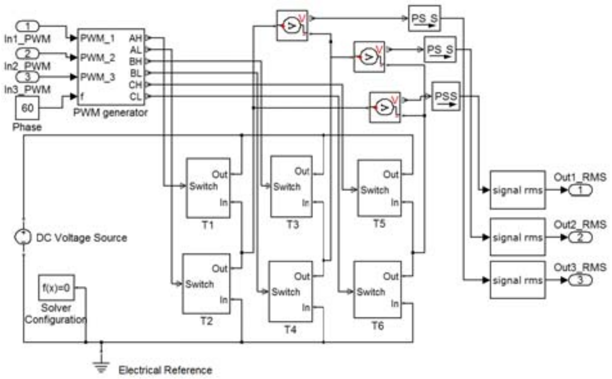

Fig. 1. Three-phase inverter´s model for a swirl water turbine

The inverter model inputs are referential (required) signals (for PWM) of single phases, outputs (for needs of control) are corresponding harmonic RMS voltages supplied to the electrical network. The input DC voltage is 565 V, which is set by other electronics blocs around this range. Attention is not paid to these electronic blocs in this paper.

3. IDENTIFICATION OF NON-LINEAR MODEL

For the design of robust linear regulation, it is necessary to use linear model of system which is supposed to be controlled. The operating point is RMS = 230 V (50 Hz), that corresponds to the specifications of the European electrical network. Single phases of the inverter are equivalent, so linearization was realized only for one phase. Direct linearization of the initial non-linear system did not lead to satisfying results. For this reason, linearization was realized by adding a compensating nonlinearity to the output of the system´s model, so that its static gain for the whole thought range of referential PWM (0 – 250 V) was approximately 1, see Fig. 2.

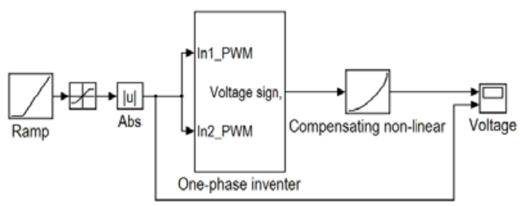

Fig. 2. Model of single-phase inverter compensating non-linear system

This way of linearization was successful only with the order of linear system n = 1, see Fig. 3.

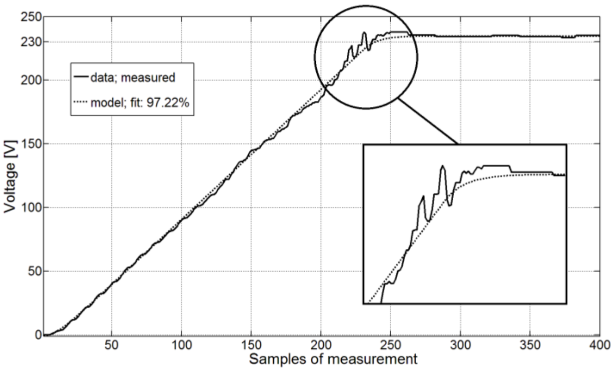

Fig. 3. One phase´s identification of single-phase inverter

This paper also deals with the design of a three-phase inverter´ s control, with the aim to improve it's behavior. For its design, we used the well-known concept of the negative feedback loop to control the dynamic behavior of the inverter. A measured RMS is subtracted from the desired value of the PWM to create the error signal, which is amplified by the controller.

4. CONTROL OF NON-LINEAR INVERTER

For the design of control component, an open loop-shaping control synthesis was used through H_∞ minimization. In order to use this method, it is necessary to know, not only the linear time invariant system (LTI) G, but also the resulting transmission from the open- loop control Gd.

The initial point of design for the controller was the simplest possible Gd with -20 dB/decade roll-off slope, so its gain corresponds to the cutoff frequency of linear model G, which behaves as a low-pass filter i.e. Gd = 75.2/s. This concept was proven to be adequate (Control 1). By simulation, it was verified that the designed regulator is able to control inverter startup (initial nonlinear model without balancing) from 0 V to a settled RMS from range [360, 70] V.

For the inverter´s verification, the same procedure was used to design also a control component for GD with lower gain, Gd = 13.3/s, which as expected, slows the behavior of the controlled system (Control 2), but expands the range of RMS controllability to the range [380, 20] V. The control component with higher gain Gd = 120/s accelerates controlling but causes overshooting (Control 3) and reduces the range of controllability to [340, 100] V.

The summary of results is demonstrated in the Fig. 4. In all cases, a very simple control component was obtained (2. order).

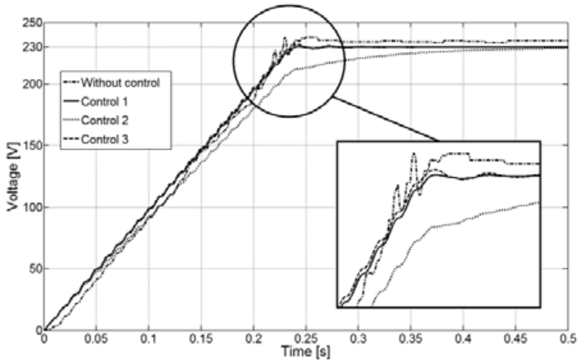

Fig. 4. Different types of required voltages resulting from comparison of controllers designs

5. CONCLUSION

The design of simple linear controller was achieved and verified relatively directly with the use of the described methodology .This controller is adequately able to control one phase of the inverter.

Identification of a published model through the addition of a compensating nonlinearity at output is a successful method. By using this method, a simplified model of swirl turbine´s single-phase inverter was identified up to the 97.22%.

The restriction of RMS regulation range to [360, 70] V does not represent an obstacle, because the range of RMS 230 V from 0 V was well achieved without overshooting within the range of controllability. There is no presumption of a required startup of RMS to the values outside the abovementioned range. For controlling the other two phases of the inverter identical control components are used. Both the identification and the design of the control component were realized in the Matlab program (pem – System Identification Toolbox, loopsyn - Robust Control Toolbox).

In the next step, the presented results will be applied and developed for a design of regulation, e.g. phasing the inverter to the electrical grid. The created solution is essential for a complex and trouble-free design of swirl turbine operation.

6. ACKNOWLEDGEMENTS

This work is supported from research plan MSM 0021630518 Simulation modeling of mechatronic systems, Development of control and sensor system for unconventional mechatronic devices FSI-S-10-29 and CZ.1.07/2.3.00/09.0162.

7. REFERENCES

Borowy, B.S. & Salame, Z.M. (1997). *Dynamic Response of a Stand-Alone Wind Energy Conversion System with Battery Energy Strange to a wind Gust*, Vol. 12, Issue 3, ISSN: 0885-8969, pp. 73–78, IEEE Transictions

Haluza, M.; Rudolf, P.; Pochylý, F. & Šob, F. (2002). *Design of a new Low-Head Turbine*, Proceedings of the XXI-st IAHR Symposium Hydraulic Machinery and Systems, Volume 1, ISBN: 3-85545-865-0, pp. 29-34, Ecole Polytechnique Federale de Lausanne, Laboratoire de Machines Hydrauliques, Lausanne, September 2002, Switzerland

Kroutikova, N.; Hernandez-Aramburo, C.A. & Green, T.C.; (2007). *State-space model of grid-connected inverters under current control mode*. ISSN: 1751-8660, Volume 1, Issue 3, pp. 329-338, Electric Power Applications, IET

Maksimovic, D.; Stancovic, A.M.; Thottuvelil, V.J. & Verghese G.C. (2001). *Modeling and simulation of power electronic converters,* pp. 898-912, Vol. 89, Issue 6, ISSN: 0018-9219, Proc. IEEE (June) (2001)

Nopporn P.; Krissanapong K.; Veerapol M.; Dhirayut Ch.; Jatturit T.; Anawach S. & Dallang M. (2010). *Modeling of single phase inverter of photovoltaic system using system identification,* pp. 462-466, ISBN: 978-0-7695-4042-9, Computer and Network Technology (ICCNT), 2010 Second International Conference, April 2010, Bangkok

Pochýlý, F. & Haluza, M. (2003). *Swirl turbine with splitter blades*, XXXV. Kraftwerktechnischen Kolloquium, pp. 14-21, Manuskriptabdruck, Institut für Universität der TU Dresden, September 2003, Dresden

Rtiz-Rivera, E.I. & Fang, P. (2004). *A Novel Method to Estimate the Maximum Power for a Photovoltaic Inverter System*, pp. 2065 – 2069, ISSN: 0275-9306, ISBN: 0-7803-8399-0, Vol. 3, Power Electronics Specialists Conference, June 2004, PESC IEEE 35th Annual