Hydro generating unit digital control system

Gorislav Erceg, Nikola Tonković, Tomislav Idžotić
University of Zagreb, Faculty of Electrical Engineering and Computing
Department of Electric Machines, Drives and Automation
Unska 3, 10000 Zagreb, Republic of Croatia
tel. +385 1 61 29 826, +385 1 61 29 651, fax. +385 1 6129705

Introduction

Hydro generating unit control system with four digital signal processors is presented in the paper. This digital control system is primarily designed for small hydro power plants. The system includes turbine governor, generator voltage control system and algorithm for unit synchronization to an electrical network. System is made up by means of 4 digital signal processors (DSP) ADMC300 (Analog Devices). All basic algorithms are performed at 14.4 kHz. Pulse width modulation (PWM) is running at 480 Hz. A thyristor converter and 2-phase AC motor are used as a turbine governor actuator. A two-quadrant transistor's (IGBT) chopper is used as a power converter for a generator exciter's excitation. Functions of the control system are experimentally verified on a hydro generating unit with double Pelton turbine and synchronous generator with DC exciter and sliding rings.

1. Background

Generating unit in hydro power plant typically consist of synchronous generator and water turbine. Each machine has its own control system. Turbine governing system is responsible for unit speed and active power control. Generator voltage control system controls generator voltage and reactive power. Both control systems today are usually based on digital microprocessors.

Digital, microprocessor based, control systems can much easier satisfy today's increased demands on control systems. Beside basic control functions, microprocessor based control systems enable implementation of most complex control algorithms including adaptive and optimal control. Digital systems have further advantages as: use of the same hardware for more different functions, easy adjustment of control parameters via operating terminal, good communication abilities with higher level control system and implementation of redundancy structure which improves system reliability and availability. Digital control systems can also include sequence control, supervision, failure diagnostic, communication and some protection functions.

Former and even modern generator voltage control systems and turbine governing systems typically use different hardware and software solutions for signal processing. This concept was logical solution for non-digital control systems. Digital signal processors allow changing of this concept. Obviously, those two control systems are different and separated, but signal processing for both systems can be made by the same hardware and with the same software tools. There are many things that are in favour of this conception especially communication between systems and sharing quite large number of signals and information between systems. Since generating unit cannot operate when turbine governor or generator voltage control system are not in function, putting them into the same device can have only positive effect on system reliability. System like that can be easily equipped with all necessary for unit synchronization to an electrical network. Considering all mentioned above, it is clear that all of this leads to reduction and simplification of hardware and makes this conception convenient, particularly for smaller units.

Conception as described above was tested on digital control system "DIRES 21", developed on Department of Electric Machines, Drives and Automation of Faculty of Electrical Engineering and Computing, Zagreb.

2. Hardware

Basic characteristics of the digital control system "DIRES 21" are: 20 analog inputs, 2 analog outputs, 24 digital inputs, 24 digital outputs, 3-phase PWM output, 4x40 char. LCD with 3 buttons for parameter change, 2 RS232 communication channels, RS422 communication channel, modem connection to a telephone line, GSM communication.

System's power electronics consists of a thyristor converter for turbine governor actuator and a two quadrant IGBT chopper for generator excitation system.

3. Software

Software is developed in the assembler programming language. Graphic programming tools are also developed. System includes library of function modules (approx. 300) and application software. Application software is easy to be made by linking different function modules for specific application within graphic, user friendly, environment. System enables implementation of most complex control algorithms with maximum sampling frequency of 14 kHz. All of this assures fast execution and flexibility of control algorithms which makes this system very suitable for fast control of drives and processes.

4. Control algorithms

There are two independent control structures: turbine governor and generator voltage control structure. There is also algorithm for unit synchronization to an electrical network.

Turbine governing system enables control of unit speed and active power with speed-droop characteristic. Turbine governor structure consists of three control circuits: P type controller of the turbine governor actuator position (AC motor rotor position), P (or PI) type controller of the turbine speed and P type controller of the active power. Turbine governor operate in speed control operating mode when the unit is not connected to an electrical network. When the unit is connected to an electrical network, turbine governor transfers to the active power control mode. Transitions between operating modes are made to be smooth. Speed and active power control are also available for unit island operation. In addition active power reference value can be set from higher level (HPP) control system and unit integrated in active power control on the power plant level.

Generator voltage control system performs control of (exciter's) excitation current and generator voltage. Reactive power control is foreseen to be included in control system also. Besides voltage control, the voltage control system provides generator excitation current limiting functions. Limiting of minimum or maximum excitation current enables operation within whole generator power chart diagram and particularly in boundary areas. This increases safety of the generator operation in the electrical power system. Generator voltage control structure consists of two control circuits: P type controller of the (exciter) excitation current and PI type controller of the generator voltage. PI type controller of the reactive power is to be built-in in the system. Voltage control system can operate in one of two operating modes: exciter excitation current control ("manual operation") or generator voltage control ("automatic operation"). All transitions between operating modes are made to be smooth. Generator voltage reference value is to be set considering generator power chart diagram.

Unit synchronization algorithm checks generator and electrical network voltage and frequency as well as phase angle between those two voltages. It sets generator voltage reference to the network voltage and turbine frequency to the network frequency plus a small amount necessary for phase angles to be matched. Algorithm takes into account time needed for generator circuit breaker to be switched-on. All of this is necessary for generating unit smooth synchronization to an electrical network.

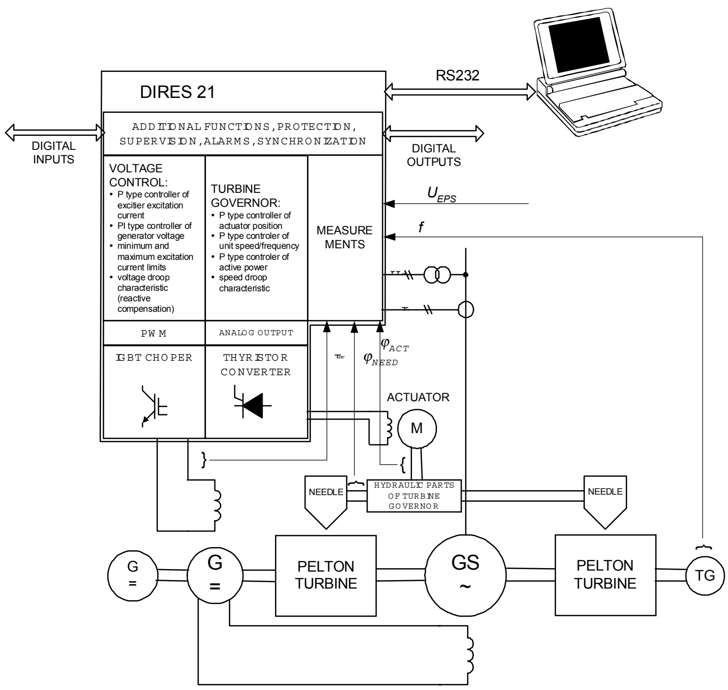


Fig. 1 Block diagram of Vinodol HPP generating unit control system

5. Experimental results

Control system is tested on the hydro generating unit with two wheels Pelton turbine (one needle per wheel, 28MW total) and synchronous generator (35MVA, 10.5kV, 1925A, $500min^{-1}$) with DC exciter. A thyristor converter is used to supply turbine governor actuator. Exciter excitation is supplied by means of two-quadrant transistor's (IGBT) chopper. System is presented on Fig. 1.

Fig. 2 shows response of frequency reference and frequency during start. Frequency reference changing rate is limited to value of 3.3 Hz per second. Generating unit reaches full speed within 60 seconds.

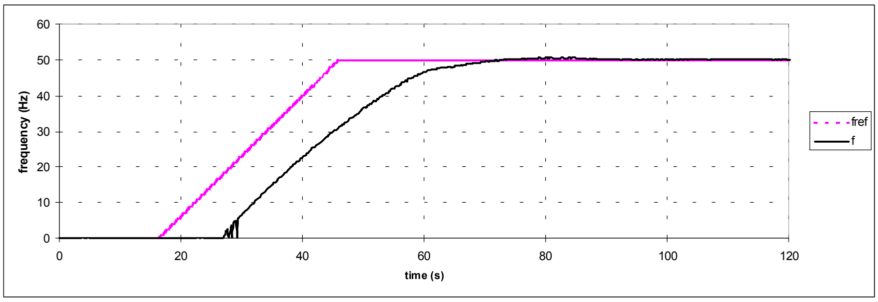


Fig. 2 Response of frequency reference and frequency during start

Responses of active power reference and active power for active power reference stepwise change from zero to 20 MW are shown in Fig. 3. Active power reference changing rate is normally limited but this response is taken without this limitation. Fig. 4 presents responses of active power reference and active power for reference stepwise change from 20 MW to zero.

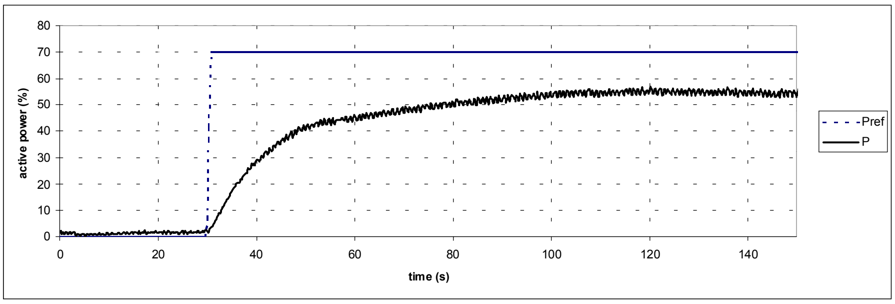


Fig. 3 Response of active power reference and active power for active power reference stepwise change from zero to 20 MW

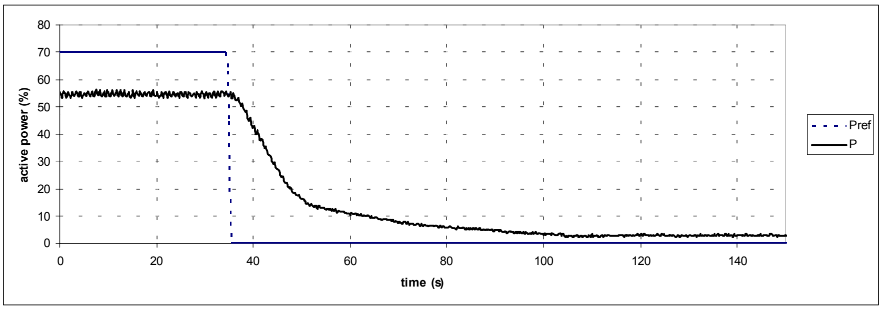
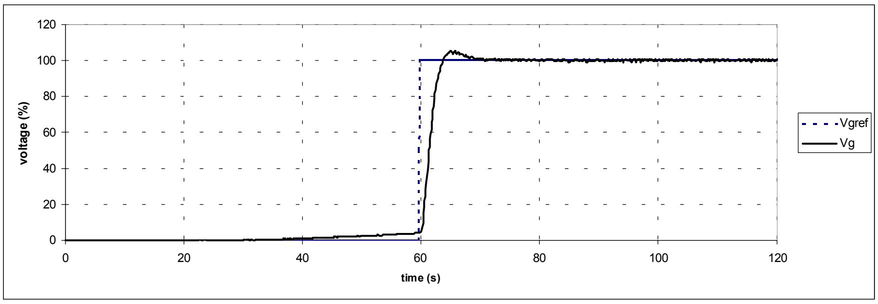
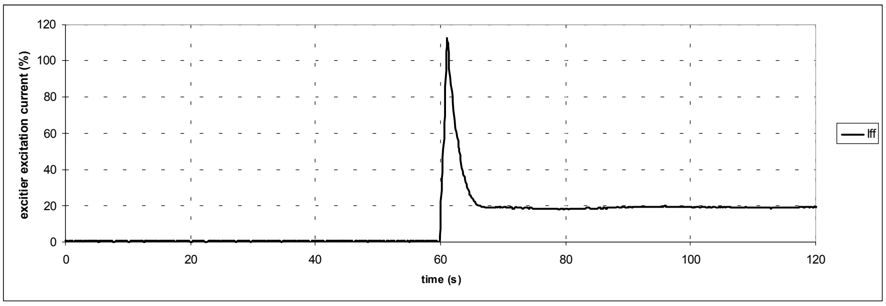


Fig. 4 Response of active power reference and active power for active power reference stepwise change from 20 MW to zero

Fig. 5 presents response of the generator voltage on reference stepwise change from zero to nominal during generating unit start. Generator voltage control system sets voltage reference to nominal when speed reaches 90% (when in "automatic operation" mode). Response of the generator voltage is relatively fast with 6% overvoltage. Generator nominal voltage is achieved within 12 seconds. Response of exciter excitation current and its reference for the same case are also presented.



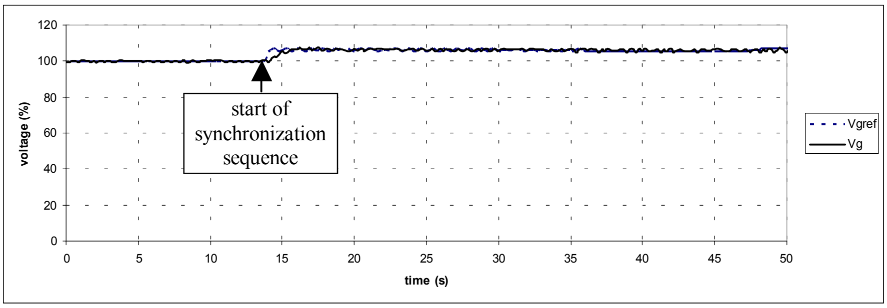
a) Generator voltage and voltage reference



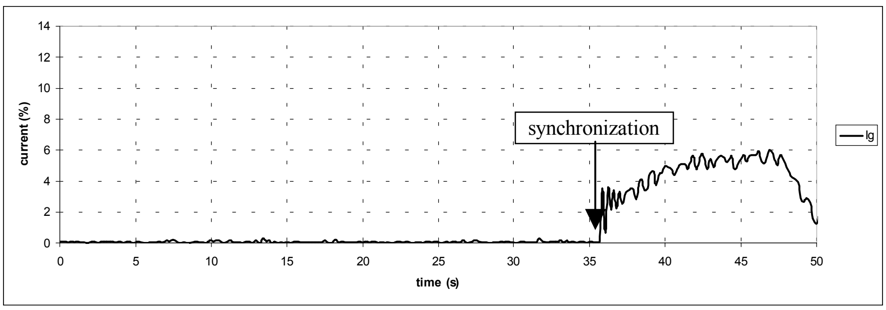
b) Exciter excitation current

Fig. 5 Response of generator voltage and response of exciter excitation current on generator voltage reference step from zero to nominal

Fig. 6 presents generator voltage, voltage reference and generator current during synchronization sequence. When the synchronization sequence starts generator voltage reference is set to the value of network voltage and the unit speed reference to the value corresponding to the network frequency increased by small amount so voltage phase angle can be matched. As said before, synchronization algorithm takes into account all necessary for unit smooth synchronization to an electrical network. Synchronization is usually achieved within approx. 30 seconds.



a) Generator voltage and voltage reference



a) Generator current

Fig. 6 Response of generator voltage, voltage reference and generator current during synchronization

4. Conclusion

This paper describes a new concept of hydro generating unit control system realized by means of four digital signal processors. Turbine governor, generator voltage control and algorithms for generator synchronisation to an electrical network are built-in in the same DSP controller. Experimental results show good behaviour of turbine governor during start sequence and load acceptance. Responses of the generator voltage on stepwise change in reference are also very good. Synchronization sequence is relatively short with small synchronization current.

References

1. **Tonković, N.**, "Digital Control System of Pelton Turbine - Generator Set", *Master's thesis*, Zagreb, 2003.
2. **Erceg, G., Erceg, R., Idžotić, T.,** "Using Digital Signal Processor for Excitation System of Brushless Synchronous Generator", *IECON 99*, San Jose, November/December 1999, p.p. 1355-1360.
3. **Erceg, G., Tonković, N., Erceg, R.,** "Excitation Limiters for Small Synchronous Generators", *11th EDPE*, 2000.
4. **Idžotić, T., Spajić, I., Padovan, L.,** "Digital regulation of sinewave inverter", *10th EDPE*, p.p. 113-117, 1998.
5. Analog Devices, "ADSP-2100 Family User's Manual", Analog Devices Inc., Third Edition, 1995.

The Authors

Gorislav Erceg was born in Vrgorac, Croatia on January 15, 1942. He received his BSEE, MSEE and Ph.D. degrees from University of Zagreb, Faculty of Electrical Engineering and Computing in 1967, 1975 and 1996, respectively. He joined dockyard Brodo-Split in Split, Croatia (1965) working in the Project Engineering Group. In 1966 at the Faculty of Electrical Engineering and Computing, Zagreb, Croatia he started as an assistant of Fundamentals of Electrical Engineering. Today as an Associate Professor, he teaches undergraduate and graduate students. Also, Mr. Erceg is a project leader of several industrial and government projects. He authored and co-authored numerous technical papers and studies in Control Engineering field, and is a member of IEEE Industrial Electronics Society, IEEE Power Society, KoREMA Society and Croatian Electric Engineering Society. For his work presented in his Master's and Ph.D. thesis, numerous papers and studies he received three awards.

Nikola Tonković was born in Zagreb, Croatia in 1971. He graduated from Faculty of Electrical Engineering and Computing in 1996. He received his MSEE degree from University of Zagreb, Faculty of Electrical Engineering and Computing in 2003. From 1996 to 1999 he worked in Elektroprojekt Consulting Engineers d.d, Zagreb, Croatia as a junior project engineer in Hydro Power Plants Section of Electromechanical Engineering Department. He was team member on several power plants projects and studies. Since 1999 he has been working as an assistant at Department of Electric Machines, Drives and Automation at Faculty of Electrical Engineering and Computing, Zagreb. His major research interests are control systems in industry and power plants.

Tomislav Idžotić was born in Zagreb, Croatia in 1971. He received his BSEE and MSEE degrees from University of Zagreb, Faculty of Electrical Engineering and Computing in 1994 and 1999, respectively. Since 1997, he has been working as an assistant at Department of Electric Machines, Drives and Automation at Faculty of Electrical Engineering and Computing, Zagreb. For his work presented in his Master's thesis and during his undergraduate study, he received two awards. His research is mostly related to digital systems for generator voltage control and induction motors control.