Modeling of Management System for Hydroelectric Power Generation from Water Flow

Kwang-Soon Choi
ICT R&D Division,
Korea Electronics Technology Institute (KETI)
Seoul, Korea
lenon@keti.re.kr

Ji-Woon Yeom
ICT R&D Division,
Korea Electronics Technology Institute (KETI)
Seoul, Korea
jiwoon.yeom@keti.re.kr

***Abstract*— Due to recent abrupt climate change and the environmental contamination, the interest in the renewable energy increases, and various types of renewable energy generation systems have been replacing the existing old ones using fossil fuels. Hydroelectric power generation is traditionally one of those clean energy solutions. Recently, new hydroelectric power generation from municipal water systems has been developed and regarded as a new or replaceable water system of new and old cities. In this paper, basic architecture of hydroelectric power generation from water pipes and information modeling is proposed in terms of management.

Keywords—hydropower, hydroelectric power, water pipe, water flow, distributed energy resource, virtual power plant

I. INTRODUCTION

Municipal water systems carry large amount of water through underground pipes. It was uneconomic and impractical to put hydroelectric generators in pipes to generate electricity by using the water flow energy because it definitely takes energy away from the water flow and finally requires more electricity to operate more powerful pumps to move the water from the source to customers. However, it becomes possible to generate electricity in case that water flows naturally from a high elevation.

In case of the Korean peninsula having seas on three sides, aqua farms are well developed and equip with water pumps which raise water from the sea. The raised sea water, through the aqua farm, flows to the sea from a higher elevation. Our hydroelectric power generation system is designed to use that water flow energy and converts it to electricity.

II. SYSTEM ARCHITECTURE

A. Waterflow-based Hydroelectric Power Generation System

The proposed architecture of waterflow-based hydroelectric power generation system is illustrated in Fig.1. In order to get energy from water flow, one or more hydraulic turbine(s) are located in (a) water pipe(s) by taking into account of the target electricity generation as well as the geographical and physical conditions such as velocity and flux of water flow in pipes, diameter of pipes, and etc. which consequently affects the design parameters for both of hydraulic turbines and gearboxes.

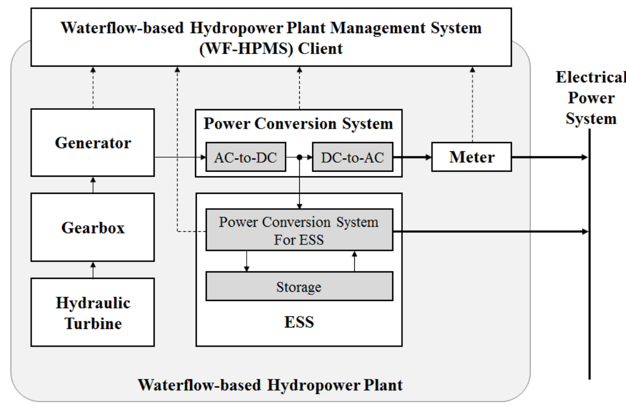

Fig. 1. Waterflow-based Hydroelectric Power Generation System

The gearbox consists of gears and gear trains to provide constant speed and torque conversion from a rotating hydraulic turbine to a generator in order to generate steady electricity. The generator converts the rotational kinetic energy into electric energy, which is usually AC power. The generated electricity can be sent to either electrical power system or Electricity Storage System (ESS) through a Power Conversion System (PCS).

For the management and control of each main component of the system, a waterflow-based hydropower plant management system (WF-HPMS) client is located at a local site or a waterflow-based hydropower plant. The WF-HPMS client gathers operating status values of each component and forwards them to the WF-HPMS server on a periodic basis or upon a request from the WF-HPMS server according to the characteristics of the gathered values. RS-485 is designated as the network interface between WF-HPMS client and each component by considering environmental characteristics of the power plant.

The WF-HPMS server, through 3G, 4G or 5G network, connects several WF-HPMS clients located at geographically remote areas as shown Fig. 2. The main function of the WF-HPMS server is to monitor the electricity generation in real-time and to diagnose fault or breakdown of a component of a local site.

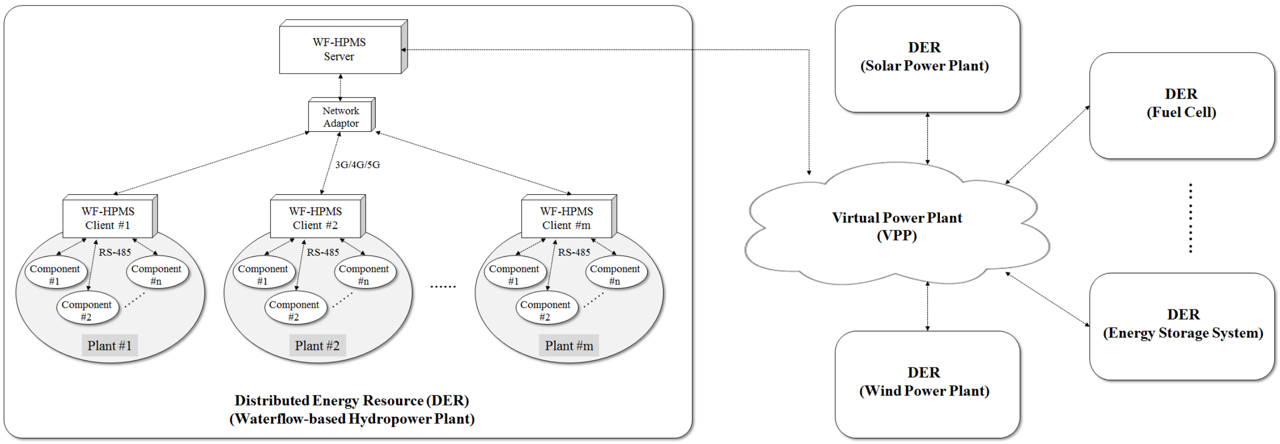

Fig. 2. Waterflow-based Hydropower Plant as one of Distributed Energy Resources

B. Distributed Energy Resource

The WF-HPMS server and WF-HPMS clients can be grouped as represented on the left side of Fig. 2, and logically regarded as a power plant so called Distributed Energy Resource (DER) even though the physical power generation occurs independently at remote areas.

C. DER for Virtual Power Plant

The waterflow-based hydropower plant as one of DERs can be connected to a Virtual Power Plant (VPP) with other DERs such as solar power plant, wind power plant and so on as depicted on the right side of Fig. 2. A VPP is a cloud-based distributed power plant aggregating heterogeneous DERs for the purposes of enhancing electricity generation.

III. Information Modeling

For the information modeling of the waterflow-based hydropower plant, the international standard, IEC 61850-7-410 [1] and IEC 61850-7-420[2] are utilized. The former specifies the additional common data classes, logical nodes and data objects required for the use of IEC 61850 in a hydropower plant. The latter defines IEC 61850 information models to be used in the exchange of information with DERs, which comprise dispersed generation devices and dispersed storage devices including reciprocating engines, fuel cells, microturbines, photovoltaics, combined heat and power, and energy storage. It also utilizes existing IEC 61850-7-4[3] logical nodes where possible, but also defines DER-specific logical nodes where needed.

A. Logical Devices and Logical Nodes for WF-HPMS Client

The proposed waterflow-based hydropower generation system in Fig. 1 is modelled as illustrated in Fig. 3 by use of IEC 61850-7-420 and IEC 61850-7-4. Logical Nodes (LNs) associated with each physical component are summarized in Table. I.

TABLE I. Logical Nodes for WF-HPMS Client

Physical Device	Logical Node	Description
WF-HPMS client	DRCT	DER controller characteristics
	DRCS	DER controller status
	DRCC	DER supervisory control
	MMXU	Measurement (from IEC 61850-7-4)
	CSWI	Switch controller (from IEC 61850-7-4)
Hydraulic Turbine and Gearbox	DCIP	Reciprocating engine
	STMP	Temperature measurement
	MPRS	Pressure measurement
	MFLW	Flow measurement
	SVBR	Vibration conditions
	MMET	Meteorological conditions
Generator	DGEN	DER unit generator
	DRAT	DER generator ratings
	DRAZ	DER advanced generator ratings
	DCST	Generator cost
Power Conversion System	ZRCT	Rectifier
	ZINV	Inverter
	MMDC	Measurements of intermediate DC (from IEC 61850-7-4)
	MMXU	Measurements of input AC and output AC (from IEC 61850-7-4)
Meter	MMXU	Measurements of input AC and output AC (from IEC 61850-7-4)
Electrical Connection Point (ECP)	DCRP	DER plant corporate characteristics at the ECP
	DOPA	DER operational authority at the ECP
	DOPR	Operational characteristics at the ECP
	DOPM	Operating mode at ECP
	DPST	Status information at the ECP
	DCCT	DER economic dispatch parameters
	DSCC	DER energy and/or ancillary services schedule control
	DSCH	DER energy and/or ancillary services schedule
Storage	ZBAT	Battery systems
	ZBTC	Battery charger

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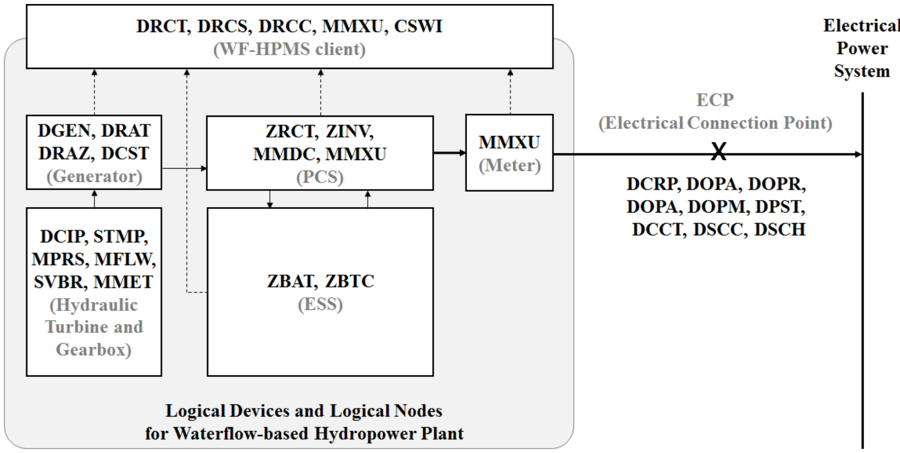

Fig. 3. Logical Devices and Logical Nodes for Waterflow-based Hydroelectric Power Generation System

B. Data Objects and Common Data Classes for Hydraulic Turbine and Gearbox

For more detailed information modeling of hydraulic turbine and gearbox, the following data objects and common data classes are utilized according to the IEC 61850-7-420, IEC 61850-7-4 and IEC 61850-7-3, which are listed in Table II.

TABLE II. DATA OBJECTS AND COMMON DATA CLASSES FOR HYDRAULIC TURBINE AND GEARBOX

Logical Node	Category	Data Object	Common Data Class (in IEC 61850-7-3[4])
DCIP	Status Information	EngOnOff	SPS (Single Point Status)
	Settings	MinSpd	ASG (Analogue Setting)
		MaxSpd	
	Controls	EngTrqSet	APC (Controllable analogue process value)
		DiagEna	DPC (Controllable double point)
	Measured Value	EngRPM	MV (Measured value)
		EngTrq	
		BlowFlow	
STMP	Status Information	TmpSt	SPS (Single Point Status)
	Settings	MaxTmp	ASG (Analogue Setting)
		MinTmp	
	Measured Value	Tmp	MV (Measured value)
MPRS	Status Information	PresSt	SPS (Single Point Status)
	Settings	MaxPres	ASG (Analogue Setting)
		MinPres	
	Measured Value	Pres	MV (Measured value)
MFLW	Settings	MatTyp	ENG (Enumerated status setting)
		MatStat	
		MaxFlwRte	ASG (Analogue Setting)
		MinFlwRte	
	Measured Value	FlwRte	MV (Measured value)
		FanSpd	
	Controls	FanSpdSet	APC (Controllable analogue process value)
	Metered Value	MtrVol	BCR (Binary Computer Reading)

C. Data Objects and Common Data Classes for Generator, Power Conversion System and Meter

Since the data objects and common data classes for a generator, a power conversion system and meters required for information modeling are usually similar to all of DERs using renewable energy such as photovoltaic systems, fuel cells and energy storages, detailed information is omitted.

D. Data Objects and Common Data Classes for WF-HPMS Client

Main functions of the WF-HPMS client are to monitor the operating status of all sub-components at the local site by measuring metered values, to exchange those information with a WF-HPMS server, and to control sub-components according to commands sent from the WF-HPMS server. In order to provide those functionalities, logical nodes including DRCT, DRCS, DRCC, MMXU, and CSWI are utilized as summarized in Table III.

IV. OPERATIONAL SCENARIO

For the operation of waterflow-based hydropower plant, scenarios such as initiation, test mode, start, monitoring (or diagnosis), stop and load control are defined as represented in Fig. 4. Though information modeling of all sub-components is designed according to the international standards as explained in Section III, only WF-HPMS clients act as an intelligent electronic device (IED) specified in IEC 61850-7-1 and exchange information with one WF-HPMS server due to the constraints of physical network interfaces (i.e., RS-485) between a WF-HPMS client and sub-components, which is usually caused by environmental constraints of the plant and the consideration of cost-effective network method for the installation of sub-components.

The interconnection between a WF-HPMS server and clients uses 3G-, 4G, or 5G-based wireless network. The WF-HPMS server will be implemented to provide GUI-based control functions of each remote plant for operators as well as operational status monitoring services for normal users.

TABLE III. DATA OBJECTS AND COMMON DATA CLASSES FOR WF-HPMS CLIENT

Logical Node	Category	Data Object	Common Data Class (in IEC 61850-7-3)
DRCT	Settings	DERNum	ING (Interger status setting)
		DERtyp	
		MaxWLim	ASG (Analogue Setting)
		MaxVarLim	
		StrDlTms	ING (Interger status setting)
		StopDlTms	
		LodRampRte	
DRCS	Mandatory	OpTmh	INS (Interger status setting)
	Status Information	ECPConn	SPS (Single Point Status)
		AutoMan	
		Loc	
		ModOnConn	
		ModOnAval	
		ModOffAval	
		ModOffUnav	
		ModTest	
DRCC	Settings	OutWSet	APC (Controllable analogue process value)
		OutVarSet	
		ImExSet	
		OutPfSet	
		OutHzSet	
		OutVSet	
		LodShutDown	
		LodSharRamp	
		DERStr	SPC (Controllable single point)
		DERStop	
		GnSync	
		EmgStop	DPC (Controllable double point)
		AutoManCtl	SPC (Controllable single point)
		LocRemCtl	
		OpModAval	
		OpModOff	
		OpModTest	
		LodModAval	
		OpTmRs	
CSWI	Status Information	OpOpn	ACT (Protection activation information)
		OpCls	
	Controls	Pos	DPC (Controllable double point)
MMXU	Measured and metered values	TotW	MV (Measured value)
		TotVAr	
		TotVA	
		TotPF	
		Hz	
		PPV	DEL (Phase-to-phase related measured values of a three-phase system)
		W	WYE (Phase to ground/neutral related measured values of a three-phase system)
		VAr	
		VA	
		PF	
		Z	
	Settings	ClcTotVA	ENG (Enumerated status setting)
		PFSign	

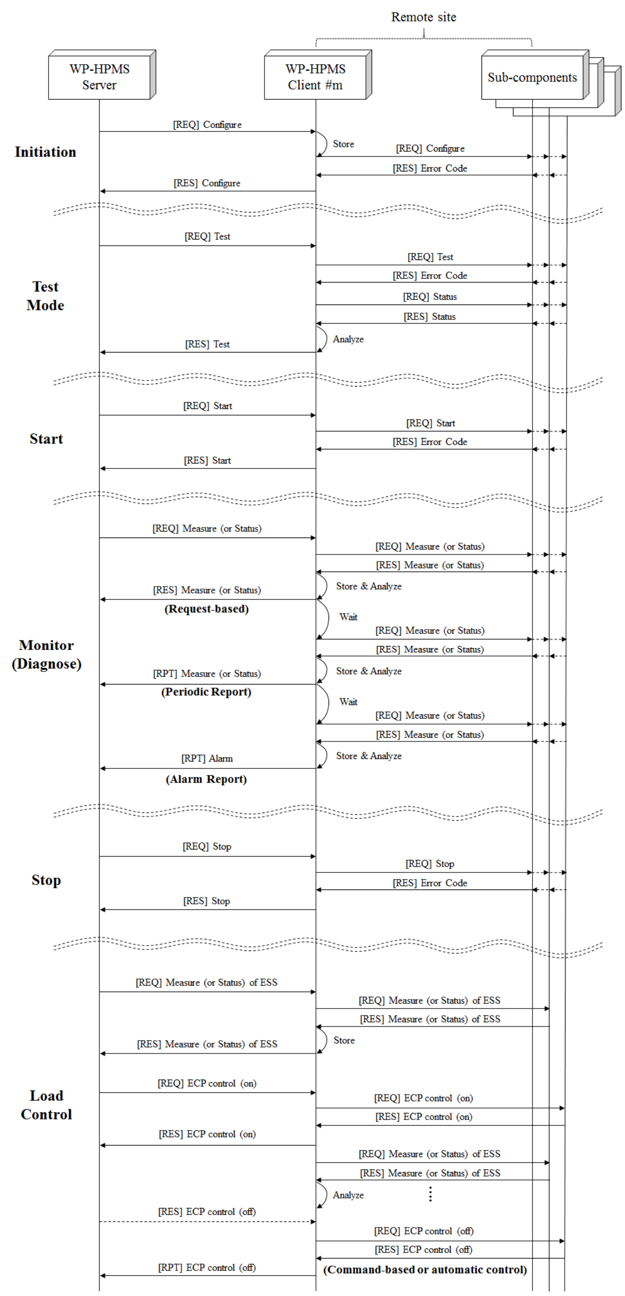

Fig. 4. Operation Scenarios of WF-HPMS server and client

The data objects, attributes and values will be transferred from WF-HPMS clients to the WF-HPMS server by use of HTTP-based XML or JSON file format as recommended in international standards.

V. CONCLUSIONS

Hydroelectric power generation has been traditionally one of clean energy generation solutions. For those reasons, most of researches have focused on the sustainability [5], efficient power generation by advancing management [6], turbine structure [7][8], and mathematical modeling of hydropower plants [9][10]. However, new hydroelectric power generation from municipal water systems has recently been developed [11], and is regarded as a new and replaceable water system of new and old cities. In this paper, in order to introduce an international standard-based new system from the beginning of deployment, basic architecture of waterflow-based hydroelectric power generation management system and information modeling, in terms of management, is designed on the basis of international standards, and proposed. A pilot plant is currently being built at an aqua farm in the southern part of South Korea, and the management system is being implemented as proposed in this paper. Further progress on the implementation and pilot test result may be represented within a year.

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