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A Study on Energy Efficiency of Vertical Water Treatment System with DC Power Supply

Young-Kwan Choi, Gang-Wook Shin, Sung-Taek Hong

***Abstract*—**Water supply system consumes large amount of power load during water treatment and transportation of purified water. Many energy conserving high efficiency materials such as DC motor and LED light have recently been introduced to water supply system for energy conservation. This paper performed empirical analysis on BLDC and AC motors and comparatively analyzed the change in power according to DC power supply ratio in order to conserve energy of a next-generation water treatment system called vertical water treatment system. In addition, a DC distribution system linked with photovoltaic generation was simulated to analyze the energy conserving effect of DC load.

***Keywords*—**Vertical Water Treatment System, DC Power Supply, Energy Efficiency, BLDC.

I. Introduction

SUPPLY of renewable energy is rapidly spreading by systematic devices such as Mandatory Renewable Energy Installation Standard (mandatory supply rate of 11% or higher applied since January 1, 2013) and Renewable Energy Portfolio Standard (RPS). In particular, supply of photovoltaic generation and fuel cell is accelerating remarkably. Since both of them produce DC power, they cannot avoid the loss from conversion to AC power. Also, the conversion loss from AC distribution to DC is expected to further increase as DC load factor is increasing by increased digital power load and development and spread of electric cars.

Water treatment plants that mainly use AC motor load for water treatment such as chemical pumps and water supply pumps are recently increasing the use of high efficiency DC motors in an effort to conserve energy, and various energy conserving high efficiency materials such as LED light are being implemented to water treatment facility buildings [1].

The purpose of this paper is to analyze power reduction according to DC power supply rate on the case of Gongju Water Treatment Plant. Also, reduction in basic power unit (kWh/m^3) of BLDC motor and AC motor will be empirically analyzed for selection of pump motor, which takes up the greatest portion of load in vertical water treatment facilities.

In addition, a simulator will be developed to analyze the energy saving rate when the load of vertical water treatment facility is converted to DC supply load.

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II. Energy Use in Water Treatment System

A. Patterns of Energy Use in Water Treatment System

Loads currently used in water treatment systems are generally supplied as AC power. Some loads (LED, computer, etc.) require conversion of AC power received into DC power.

Table I classifies the water treatment system of Gongju Water Treatment Plant according to the power type of load. In case of AC load, effective power was computed based on apparent power of the facility by applying power factor of 0.92 [2].

As shown in Table I, about 23% of the load system can be directly supplied as DC power. Since such DC power supply systems require 1~3 conversions of existing AC power to DC power, power conversion process results in a loss.

As in Table II, the ratio of electricity bill in important production costs of waterworks is 52.3%. Therefore, power conversion loss can be reduced in the next-generation water treatment system to reduce water treatment cost through direct supply of DC power without AC/DC conversion.

B. Change in Power Energy of Water Treatment System According to DC Power Supply Rate

This study assumed a case in which DC load (24% of overall effective power) in "2.1 Water Treatment System" is directly supplied as DC power without power conversion process in order to analyze power demand and power reduction of existing water treatment system according to DC power supply rate. Also, monthly power demand when DC power rate is 0% was selected as 130,191 kWh (mean power consumption of Gongju Water Treatment Plant for October ~ December 2009).

When existing AC/DC conversion efficiency was assumed to be 90%, the following results were obtained for the overall water treatment system according to DC power rate.

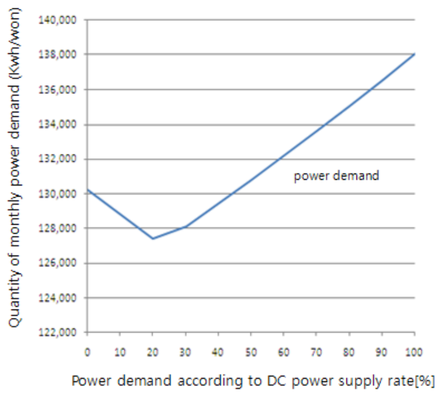

Fig. 1 Power demand according to DC power supply rate

TABLE I
WATER TREATMENT SYSTEM OF GONGJU WATER TREATMENT PLANT

	Power						
	Apparent power			Active power			
Average demand quantity (ton/month)	total load (kVA)	AC load (kVA)	DC load (kVA)	total load (kW)	AC load (kW)	DC load (kW)	Quantity of power demand (kWh/month)
360,000	1466.36	1135.6	330.76	1375.51	1044.75	330.76	130,191
	100%	77%	23%	100%	76%	24%	

TABLE II
IMPORTANT PRODUCTION COST BREAKDOWN OF WATERWORKS

	total	electric charges	maintenance expenditure	holding cost	chemicals	sludge disposal cost	communication cost
Ratio (%)	100	52.3	`26.7	9.1	7.5	3.0	1.4

As in Fig. 1, power demand of water treatment system is reduced until DC power supply rate reaches 24%. When DC power supply rate is further increased, power demand increases again in order to convert AC power into DC power.

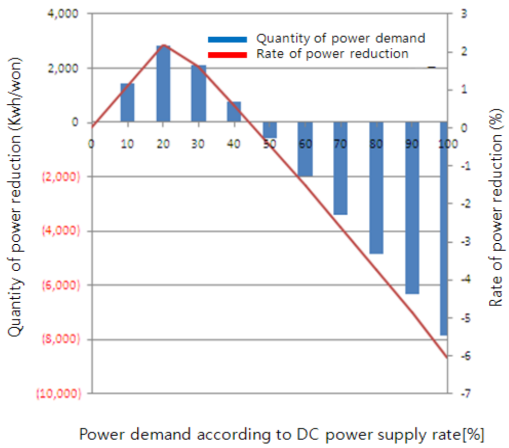

Fig. 2 Power reduction according to DC power supply rate

When DC power supply rate exceeds 40%, power consumption becomes larger than existing water treatment system as shown in Fig. 2.

III. ENERGY USE IN DC DISTRIBUTION WATER TREATMENT SYSTEM

A. Energy Use in DC Distribution Water Treatment System

Motors can be largely divided into AC motor, DC motor, and motor that can use both AC and DB. Motors that use DC power can be classified into DC motor and BLDC (Brushless DC) motor. AC motors can be classified into synchronous motor and induction motor. Most of existing motors used for operation of pumps are induction motors. Eddy current flows in the rotor of induction motor to generate force. This eddy current causes additional loss, which results in decreased efficiency compared to DC motors. Also, since it is difficult to maintain equilibrium between main winding and auxiliary winding of single-phase induction motor, it shows lower efficiency than 3-phase induction motor. Such phenomenon is more strongly shown when the motor is used for operation of pumps. Due to high resistance design on the conventional island intended to satisfy initial starting torque, actual pump motors have extremely low efficiency of about 40%.

In general, AC induction motor and DC motor widely used in industrial fields show large size, torque characteristics according to speed, heating, low efficiency, and difficulty in maintenance. However, there is a trend of gradual increase in use of brushless DC (BLDC) motor in industrial fields that require control of speed and torque.

BLDC motor refers to DC motor with an electronic rectifier installed in place of mechanical contacts such as brush and commutator. As a high performance motor, BLDC motor shows constant torque characteristics and excellent speed of direction change at all speed ranges. It uses less than half of capacity for identical output compared to general DC and AC motors. Fig. 3 shows a BLDC motor system [3]-[5].

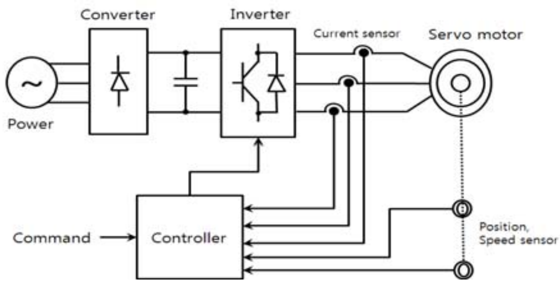

Fig. 3 Diagram of BLDC

In this study, BLDC pump motor and AC pump motor systems for water supply were constructed as shown in Fig. 4 and comparatively analyzed to verify efficiency of BLDC motor.

(a) (b)

Fig. 4 (a) Test instrument for comparison, (b) Controller of test instrument

In the comparison test result, reduction effect of 7% was shown at 1,400 rpm. The reduction effect increased with decreasing speed (25% reduction on average at 1,400 ~ 600 rpm).

TABLE III
WATER TREATMENT SYSTEM OF GONGJU WATER TREATMENT SYSTEM ACCORDING TO DC POWER SUPPLY RATE (WHEN AC MOTOR IS REPLACED TO BLDC)

DC power rate (%)	power				
	Demand (kWh/month)	AC supply (kWh/month)	DC supply (kWh/month)	Reduction (kWh/month)	Reduction rate (%)
0	99,761	99,761	0	30,430	23.37
10	98,665	88,798	9,867	31,526	24.22
20	97,593	78,074	19,519	32,598	25.04
30	96,543	67,580	28,963	33,648	25.85
40	95,516	57,310	38,206	34,675	26.63
50	94,511	47,255	47,256	35,680	27.41
60	93,526	37,410	56,116	36,665	28.16
70	94,634	28,390	66,244	35,557	27.31
80	95,662	19,132	76,530	34,529	26.52
90	96,713	9,671	87,042	33,478	25.71
100	97,788	0	97,788	32,403	24.89

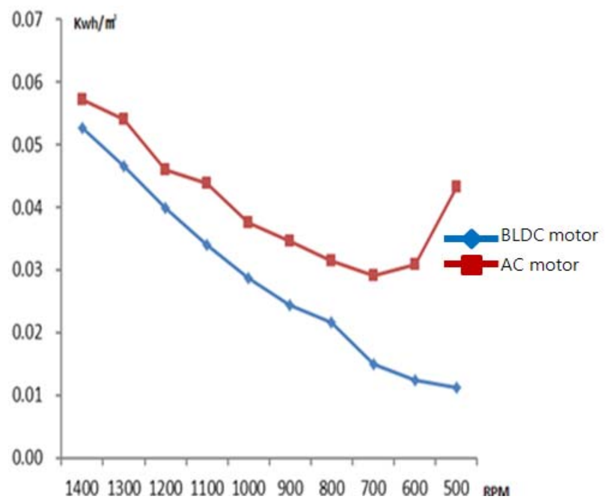

Fig. 5 Comparison of basic power unit (kWh/㎥) between BLDC motor and AC motor

B. Change in Power of "BLDC Water Treatment System" According to DC Power Supply Rate

The existing water treatment system was assumed to include a DC power supply facility (load in Table I) and replace AC motor by BLDC.

Power reduction was analyzed with an assumption that the load of AC motor takes up 46% of overall load based on the facility data of Gongju Water Treatment Plant.

When existing AC motor is replaced by high performance BLDC motor, power reduction is 30,430 kWh as shown in Table III. This corresponds to 23.37% of existing power demand. Such transition of AC motor to DC increases the ratio of DC power facilities in the water treatment system. (DC power rate increased from 24% to 60%)

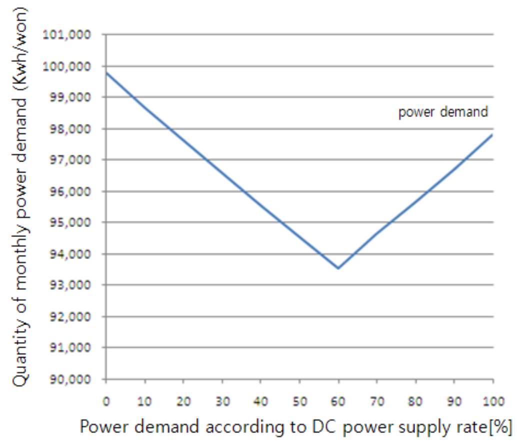

Fig. 6 Power demand according to DC power supply rate

As in Fig. 6, power demand of water treatment system decreases until DC power supply rate approaches 60%. It increases again when the rate further increases due to conversion loss from conversion of AC power to DC power.

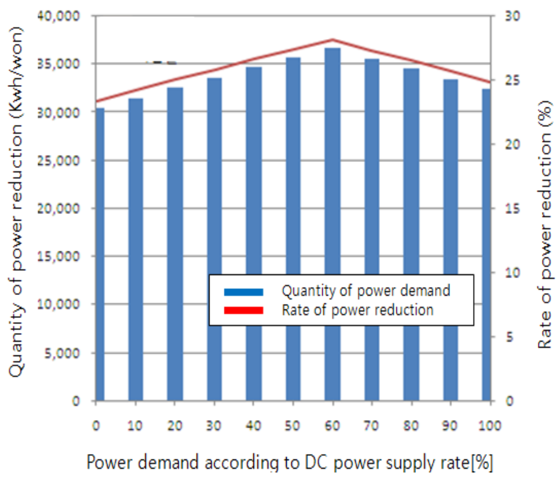

Fig. 7 Power reduction according to DC power supply rate

Since replacement to BLDC shows excellent power reduction efficiency, reduction effect can exceed 20% of power consumption in existing water treatment system regardless of changes in DC power supply rate. Therefore, replacement of existing motors with BLDC motor is a method applicable to the vertical water treatment system, which is a next-generation water treatment system. High efficiency and low capacity is one of advantages of BLDC motor, and they can reduce electricity bill among important production costs of tap water. In addition, additional reduction in maintenance expenses can be anticipated from ease of maintenance on BLDC motor.

IV. Improvement in Energy Efficiency with Application of DC Load

A. *Composition of Simulation*

Energy reduction effect can be expected from application of DC supply and BLDC in existing water treatment systems. Accordingly in this study, a DC distribution system was simulated to analyze energy reduction efficiency according to the change in DC load.

Composition of the DC system for simulation is as shown in Fig. 8. AC 380V is supplied from the system, and power is supplied to AC load. Also, PV and BIPV are linked to AC bus and supply DC power to DC load of vertical water treatment facility. Power supplied from the system and photovoltaic power are supplied to the AC bus load and DC bus load. When power is supplied to DC bus, 48V DC power is supplied through AC / DC converter.

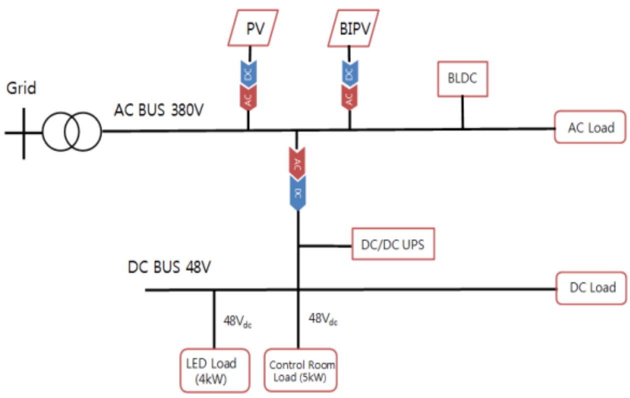

Fig. 8 Composition of DC distribution system

The system was configured using MATLAB / Simulink. The system was programmed in connection with GUI for user convenience and generality. When each load in the DC Equipment Installation box on the left side of GUI screen is checked as shown in Fig. 9, load can be converted to DC supply load. When the option is unchecked, existing load is used.

Improvement in efficiency from change to DC supply load compared to existing load can be computed. The list of loads in the vertical water treatment facility used by simulation is as shown in Table IV [1].

TABLE IV
LIST OF ELECTRIC SYSTEMS IN THE VERTICAL WATER TREATMENT FACILITY

NO	EQUIPMENT	Q'TY			MOTOR		Operation Time (hr/day)
		Q'TY	C	SB	POWER (V)	RATED (KW)	
1	UF Feed Pump	6	4	2	380	4.0	22.3
2	Auto Strainer	4	4		380	0.4	0.5
3	UF Backwash Pump	2	1	1	380	2.2	2.2
4	NaOCl Dosing Pump	2	1	1	380	0.2	0.016
5	NaOH Dosing Pump	2	1	1	380	0.2	0.016
6	Citric Acid Dosing Pump	2	1	1	380	0.2	0.005
7	MF CIP Pump	2	1	1	380	1.1	0.03
9	U.V Sterilizer	2	1	1	380	1.5	24
10	Ozone Generator	1	1	-	380/220	0.5	24
11	Drain Pump	2	1	1	380	2.2	4
12	Cooling Water Feed Pump	2	1	1	380	0.37	24
13	Chiller Unit	1	1	-	380	0.75	24
14	Water supply Pump	2	1	1	380	15	12
15	Air Compressor	2	1	1	380	1.5	1
16	PACL Dosing Pump	5	4	1	380	0.2	24
17	Lighting installation	140	140	0	220	0.032	12
18	Fire extinguishing facilities	25	25	0	6	0.006	24
19	CCTV	10	10	0	12	0.003	24
20	Air conditioning and heating equipment	5	5	0	380	11	-
21	Control Power	1	1	0	220	3	24

B. *Simulation Result*

From the list of loads in Table IV, BLDC motor was selected and applied instead of pump AC motor. Lighting fixture was replaced by LED and control power was configured as DC power.

The simulation result according to setting conditions and change in DC supply load is as follows.

1) Setting conditions 1

- Increase in efficiency by LED: 30%
- Converter efficiency: 96%
- Increase in efficiency of supervision and control facilities: 30%
- Increase in efficiency by BLDC: 10%
- Selected load: UF Backwash Pumps, NaOCl Dosing Pump, NaOH Dosing Pump, Citric Acid Dosing Pump, MF CIP Pumps, Cooling Water Feed Pumps, PACL Dosing Pumpsand, Water Supply Pump2ea, Drain pump2ea, LED, Control Power
- Simulation result: 8.1% increase in efficiency
- Except for UF feed pump, efficiency did not exceed 10% when other power loads were added and simulated under identical conditions. UF feed pump shows largest power consumption among motor loads, followed by water supply pump. Other loads either have short time of operation or small motor capacity, resulting in

insignificant effect on energy efficiency.

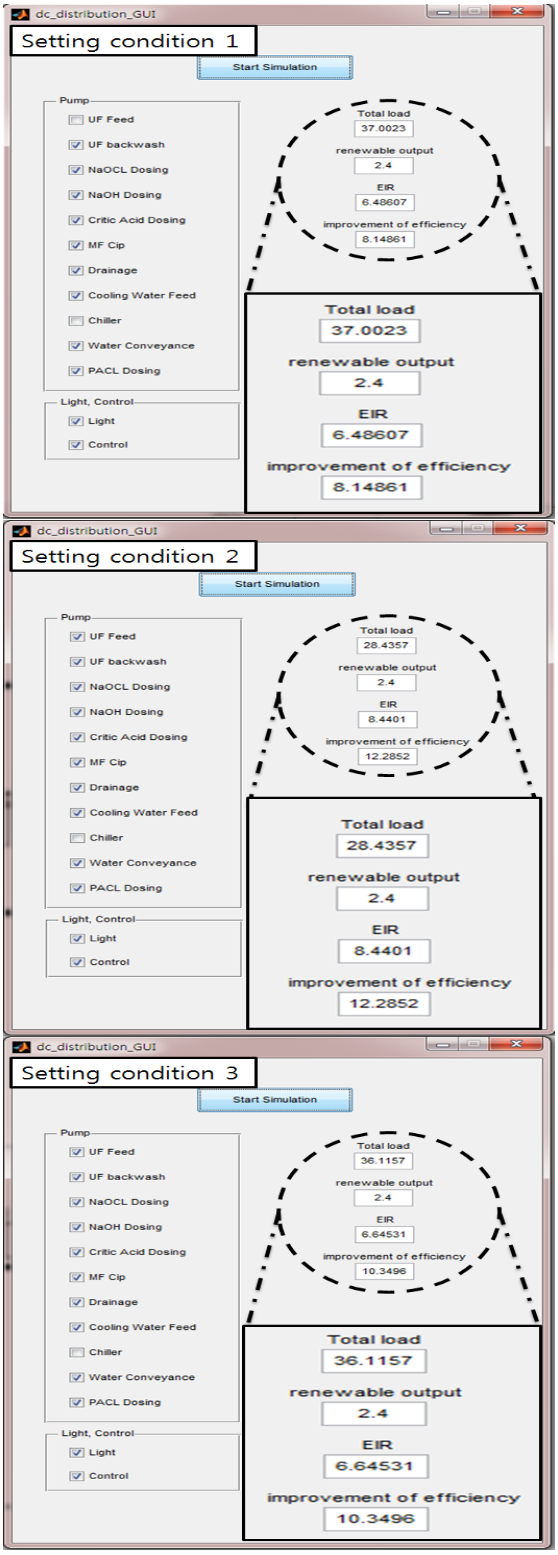

Fig. 9 Simulation result

2) Setting conditions 2

- Increase in efficiency by LED: 30%
- Converter efficiency: 96%
- Increase in efficiency of supervision and control facilities: 10%
- Increase in efficiency by BLDC: 10%
- Selected load: UF Backwash Pumps, NaOCl Dosing Pump, NaOH Dosing Pump, Citric Acid Dosing Pump, MF CIP Pumps, Cooling Water Feed Pumps, PACL Dosing Pumpsand UF Feed Pumps 4ea, Water Supply Pump1ea, Drain Pump1ea, LED, Control Power
- Simulation result: 10.3% increase in efficiency

3) Setting conditions 3

- Increase in efficiency by LED: 30%
- Converter efficiency: 96%
- Increase in efficiency of supervision and control facilities: 30%
- Increase in efficiency by BLDC: 10%
- Selected load: UF Backwash Pumps, NaOCl Dosing Pump, NaOH Dosing Pump, Citric Acid Dosing Pump, MF CIP Pumps, Cooling Water Feed Pumps, PACL Dosing Pumpsand UF Feed Pumps 4ea, Water Supply Pump1ea, Drain Pump1ea, LED, Control Power
- Simulation result: 12.2% increase in efficiency

V. Conclusion

In this paper, power reduction according to DC power supply rate was analyzed on the case of Gongju Water Treatment Plant. Also, basic power unit (kWh/m^3) reduction of BLDC motor and AC motor was empirically analyzed to select pump motor, which takes up the greatest part of load in vertical water treatment facilities.

Furthermore, a simulator was developed and used to analyze the energy reduction rate when load of vertical water treatment facility is converted to DC supply load. As a result, maximum energy reduction effect was found to be 12.2%. Greater improvement in efficiency can be anticipated when all pump motors with large loads, such as water supply and drainage pumps, are supplied in DC power and efficiency of supervision and control facility is set to maximum value of 30%.

When constructing power distribution system for a vertical water treatment system in the future, it would be necessary to establish DC power supply and select DC load based on economic feasibility analysis "considering material expense and energy reduction rate of power facilities".

Acknowledgment

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