

On-Site Performance Test for a Small Scale Variable Speed Hydropower System

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■ Increase of small hydropower

- High variation of flow rate
- Swage treatment plant
- Widely used by general citizen

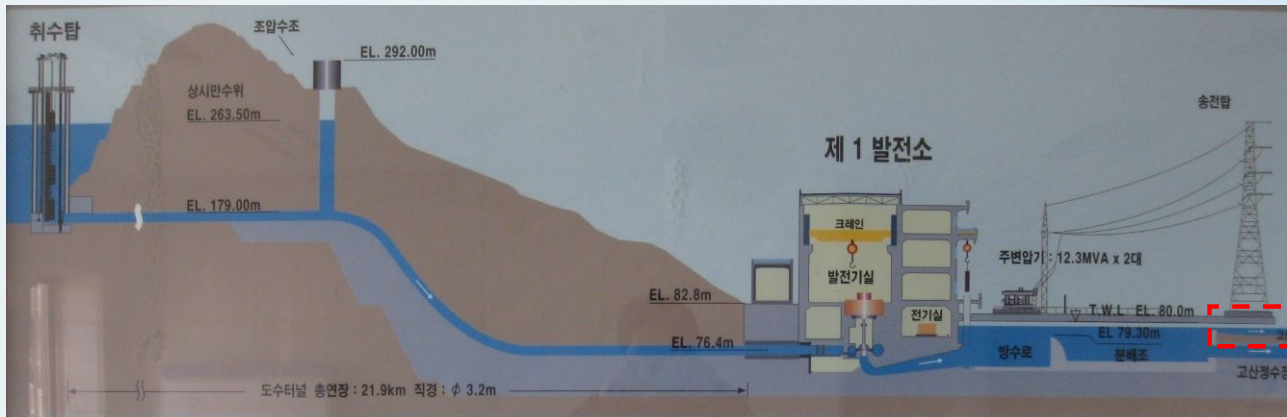
■ Small hydropower system that citizen want

- No manual operation
- Continuous operation automatically although discharge rate is so low

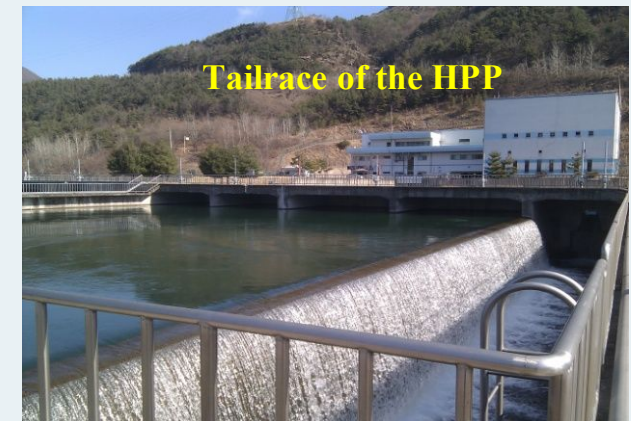
■ Variable speed hydropower system

- Turbine speed variation with high efficiency
- Produced frequency is varied with rotational speed.
- Power converter system is needed to connect to the grid.

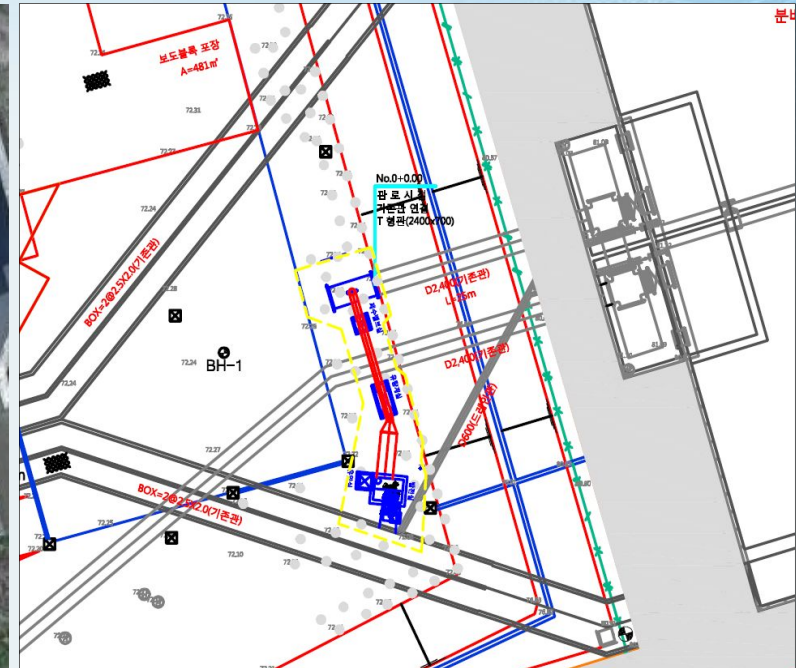
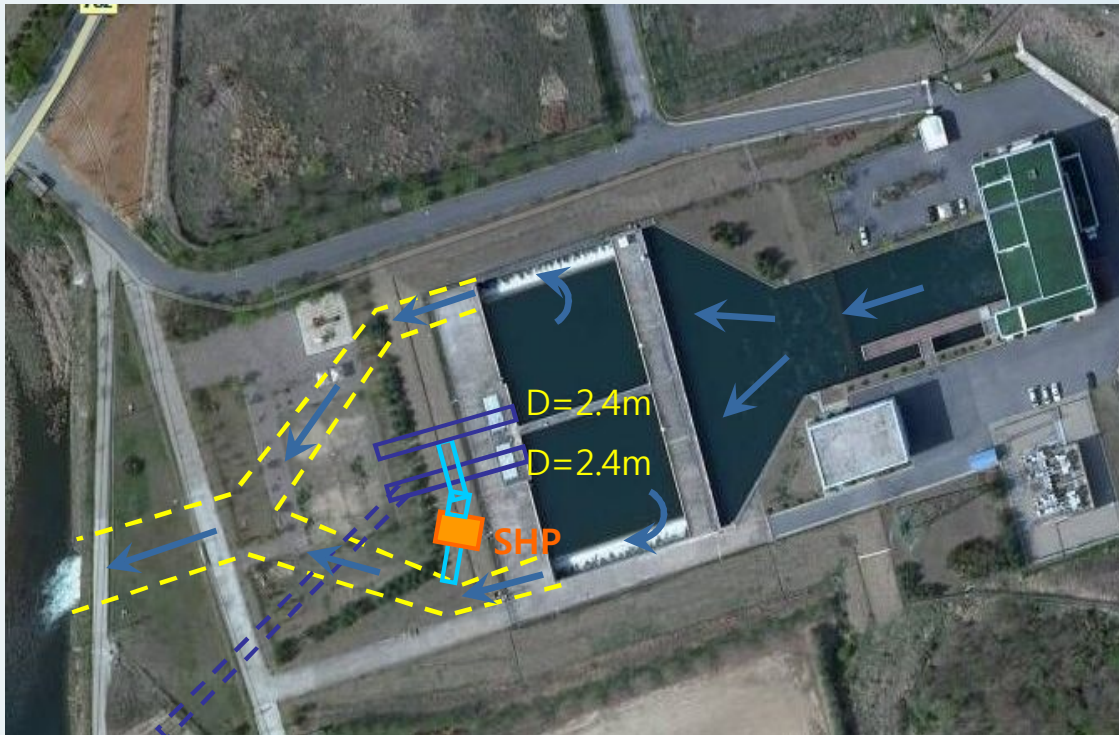
Investigation of proper site



- ✓ Yongdam 1st hydropower plant
- ✓ Some of the discharged water flows to the water treatment plant and the rest of water flows to river.
- ✓ The rest water is able to be used by a variable speed SHP.
 - ✓ Gross head : 11.28 m
 - ✓ Max. flow rate : 6.72 m³/s

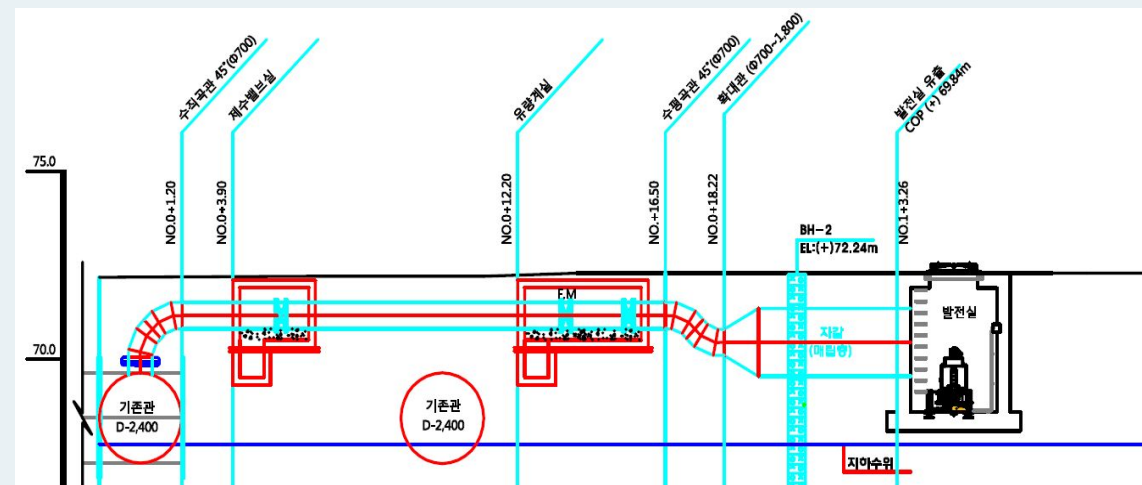


Construction Plan

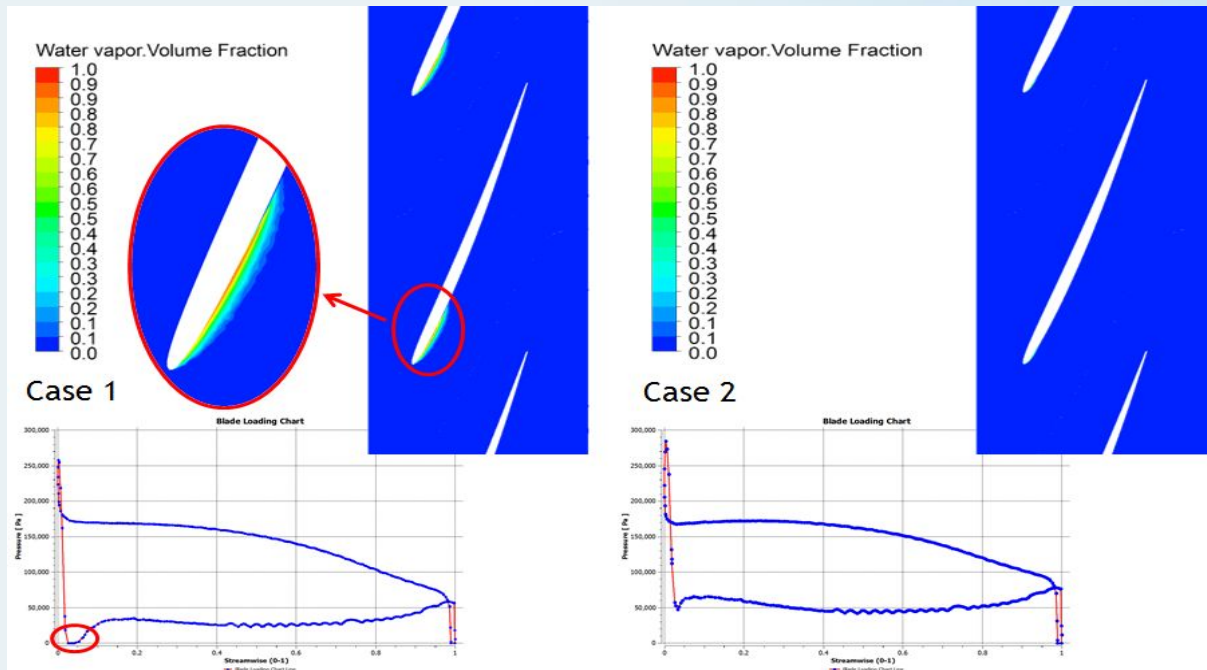


For field testing

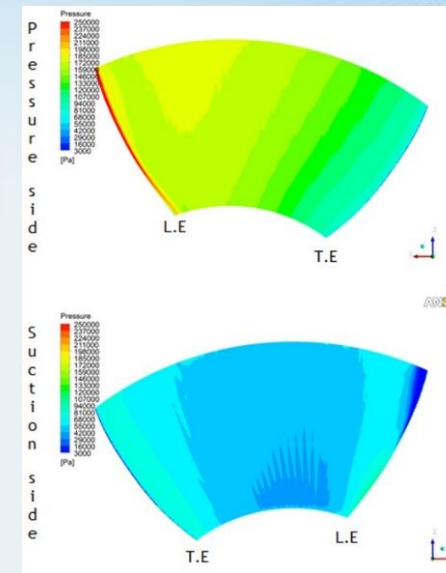
- Electromagnetic flowmeter (D800) in the straight pipe line
- Differential pressure transducer between inlet casing and draft tube



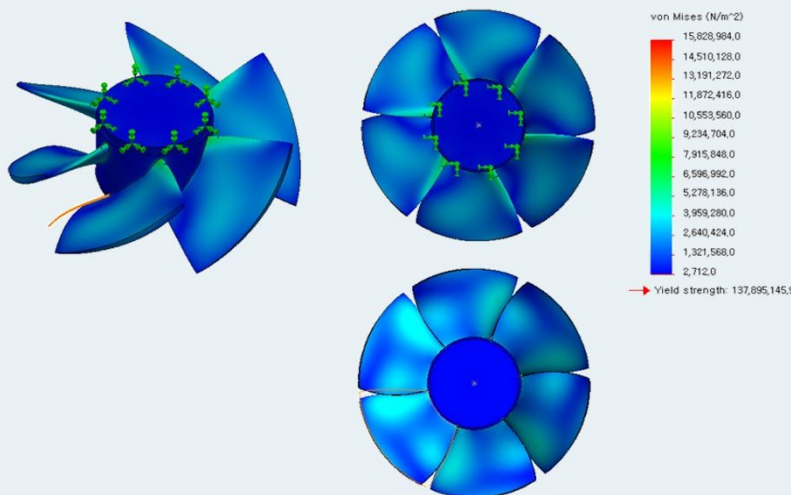
Runner Design



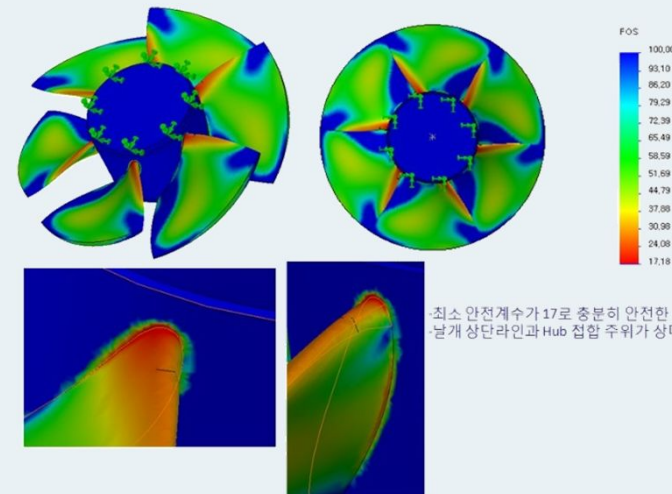
Pressure characteristics of pre-designed blades



Static pressure on blade P.S. and S.S.



Von-Mises Stress



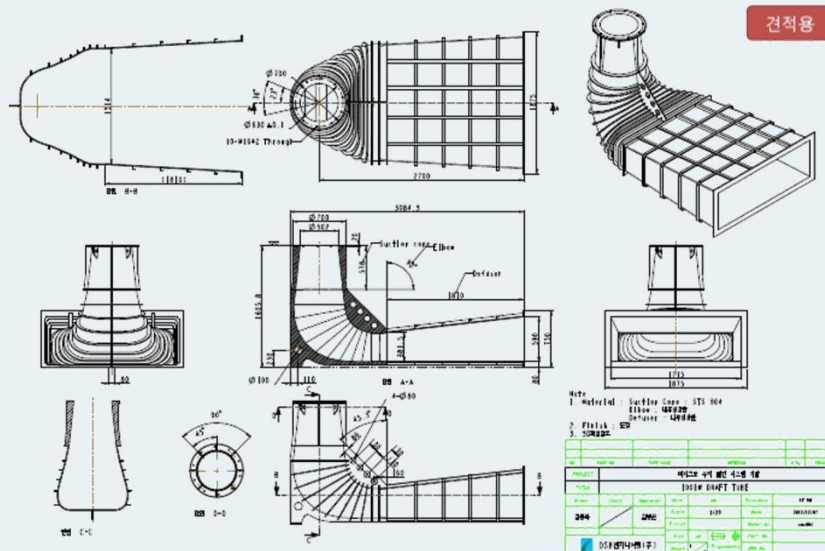
Safety factor

최소 안전계수가 17로 충분히 안전한 구조.
날개 상단라인과 Hub 집합 주위가 상대적으로 약함.

Manufactured Runner & Draft Tube

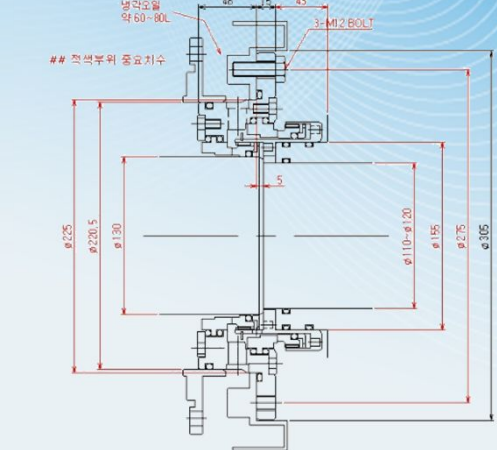
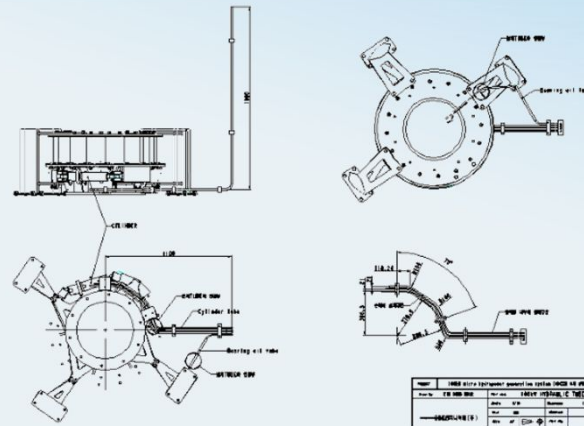
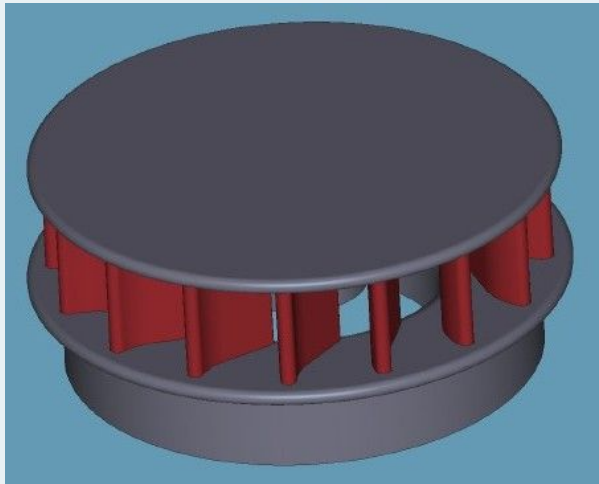


Runner



Draft tube

Guide vanes & Additional Parts



Guide vane

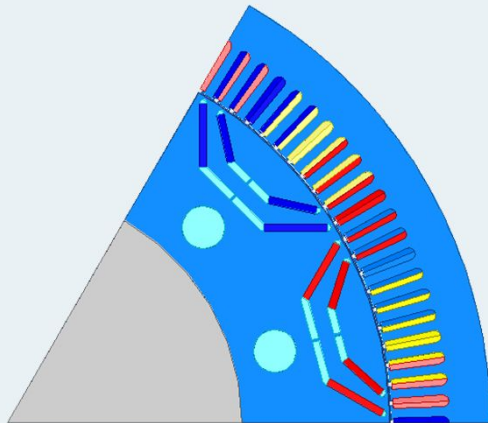


Control device

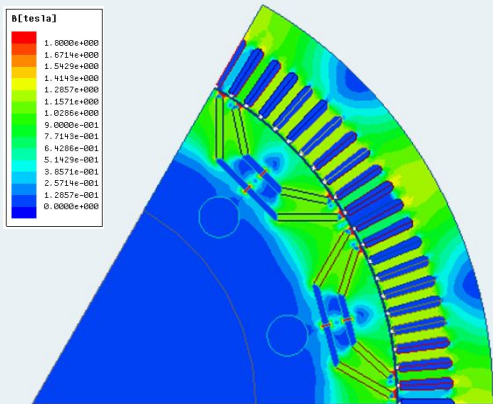


Thrust bearing

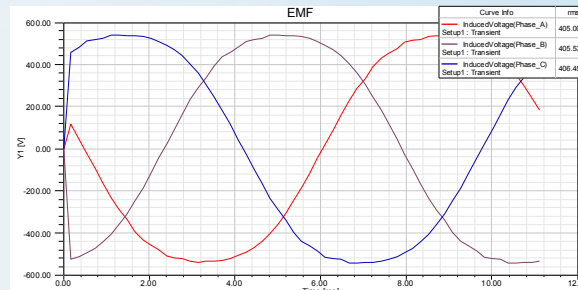
Design of PMSG



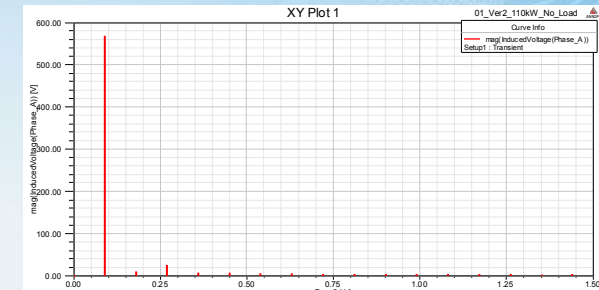
Magnetic distribution



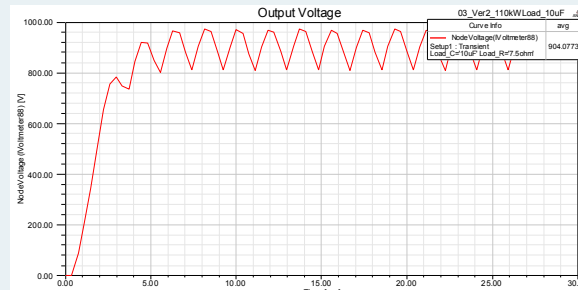
Electromagnetic analysis



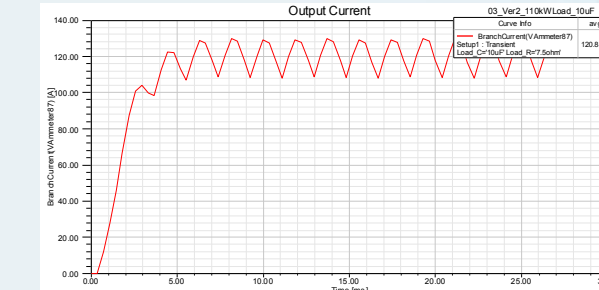
Counter electromotive force



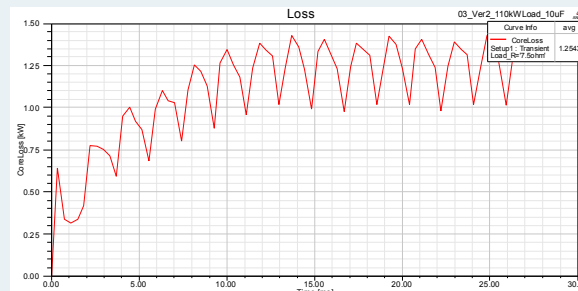
Total harmonic distortion



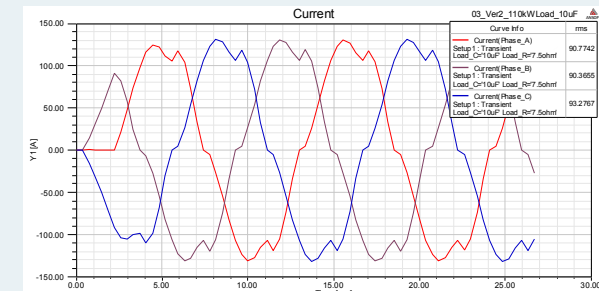
Voltage (@900rpm)



Current (@900rpm)



Core Loss



Copper Loss

$$\text{Copper Loss} = 3 \cdot I_{ph}^2 \cdot R_{ph_Coil} = 3 \cdot 91.5^2 \cdot 0.0469 = 1.178 [\text{kW}]$$

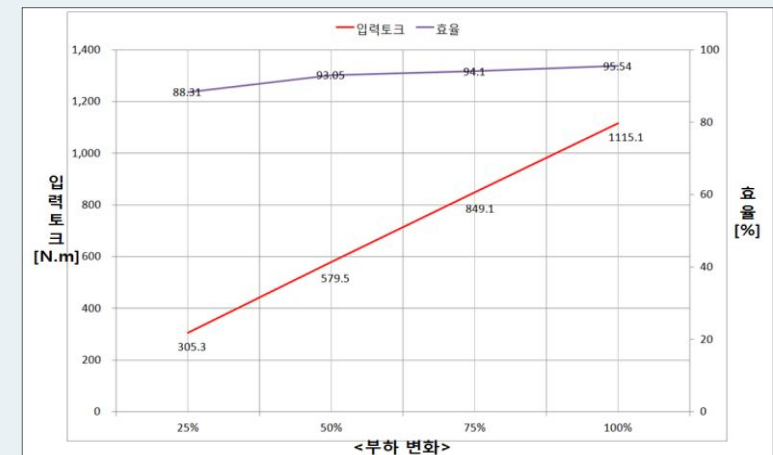
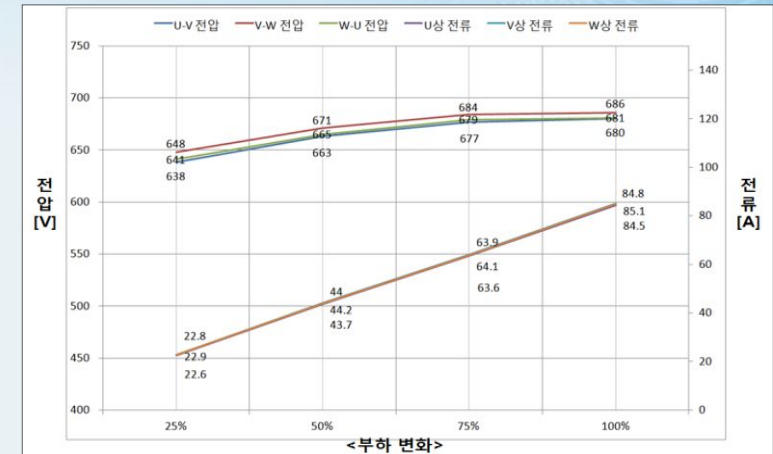
Output Voltage [Vdc]	Output Current [Adc]	Output Power [kW]	Copper Loss [kW]	Core Loss [kW]	Efficiency [%]
904	120.8	109.2	1.18	1.25	97.8

Performance Test of Generator

Test items			
Structure design	Resistance	Performance	Efficiency
	Insulation Resistance		THD
	Dielectric withstand voltage		Over speed



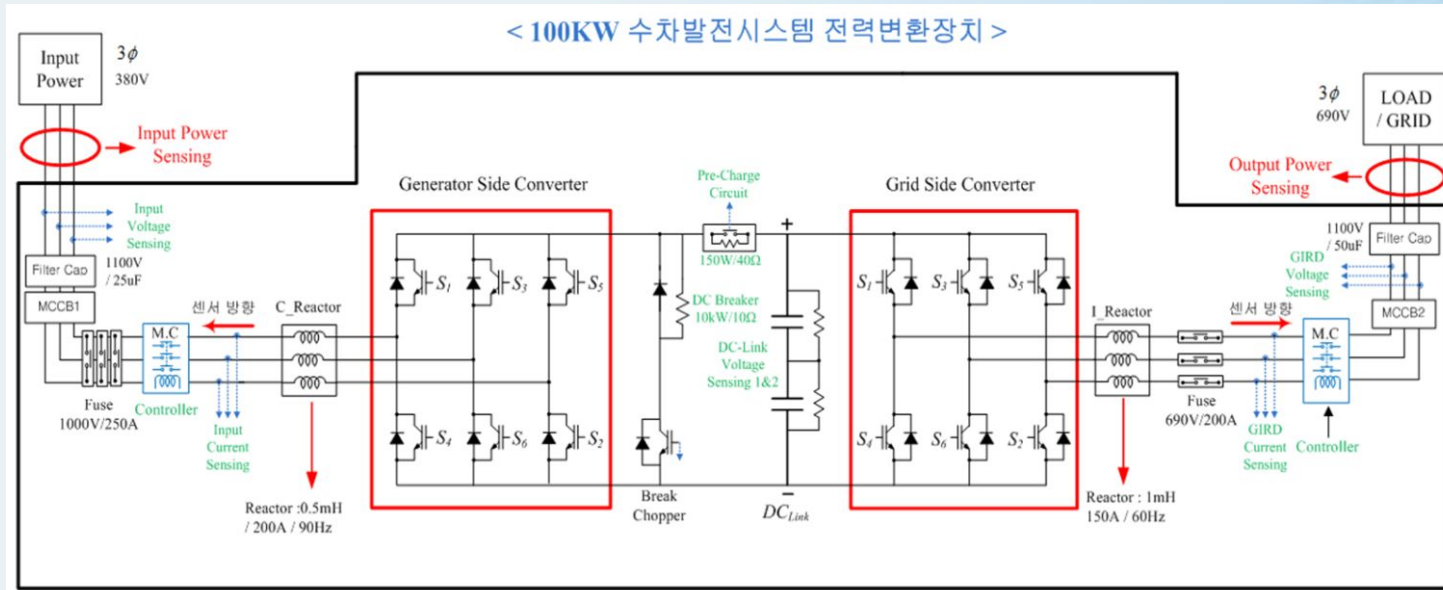
150kW dynamo testing system



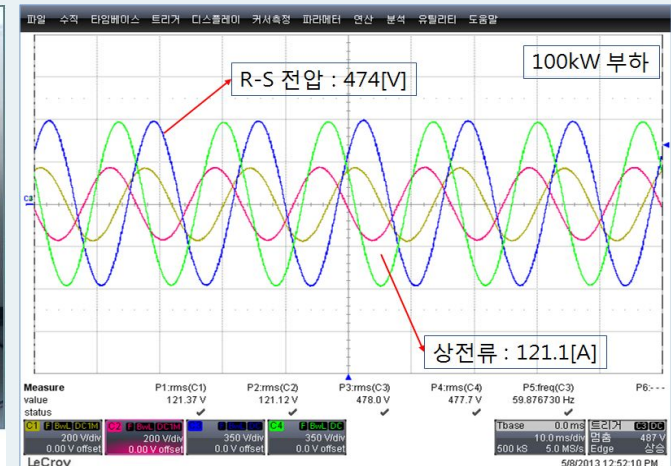
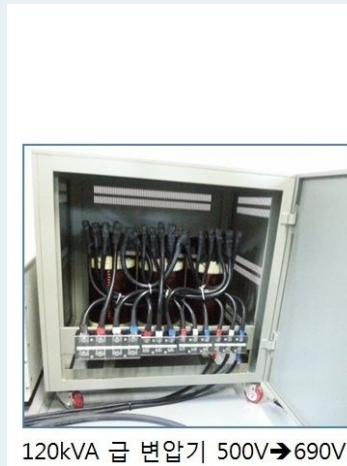
Torque & Efficiency for various loads

※ Max. efficiency : **95.54%**

Design of Power Converter

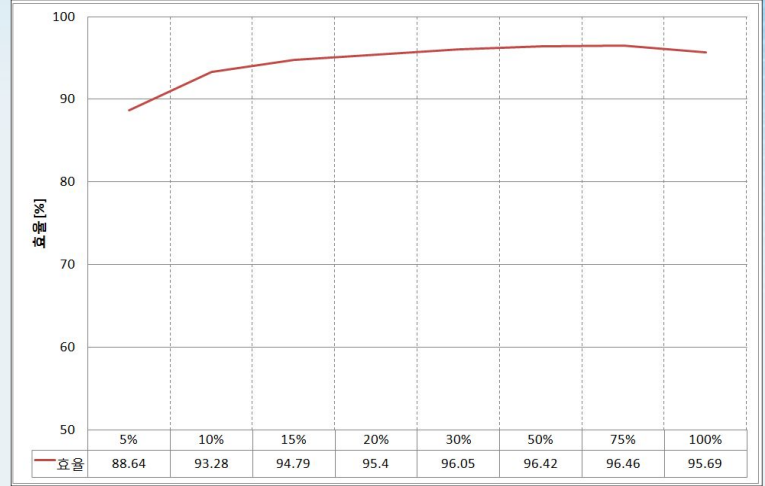


Circuit diagram for a power converter



Performance Test of Power Converter

Test items			
Insulation	Insulation resistance	Steady state characteristics	THD
	Withstand voltage		Leakage current
			Efficiency



정격전력	5%	10%	20%	30%	50%	100%
효율	88.64%	93.28%	95.40%	96.06%	96.42%	95.69%

Efficiency for loads

→ Euro efficiency

$$\eta_{EU} = 0.03\eta_{5\%} + 0.06\eta_{10\%} + 0.13\eta_{20\%} + 0.10\eta_{30\%} + 0.48\eta_{50\%} + 0.20\eta_{100\%}$$

$$\eta_{EU} = 0.03 \times 88.64\% + 0.06 \times 93.28\% + 0.13 \times 95.40\% + 0.10 \times 96.05\% + 0.48 \times 96.42\% + 0.20 \times 95.69\%$$

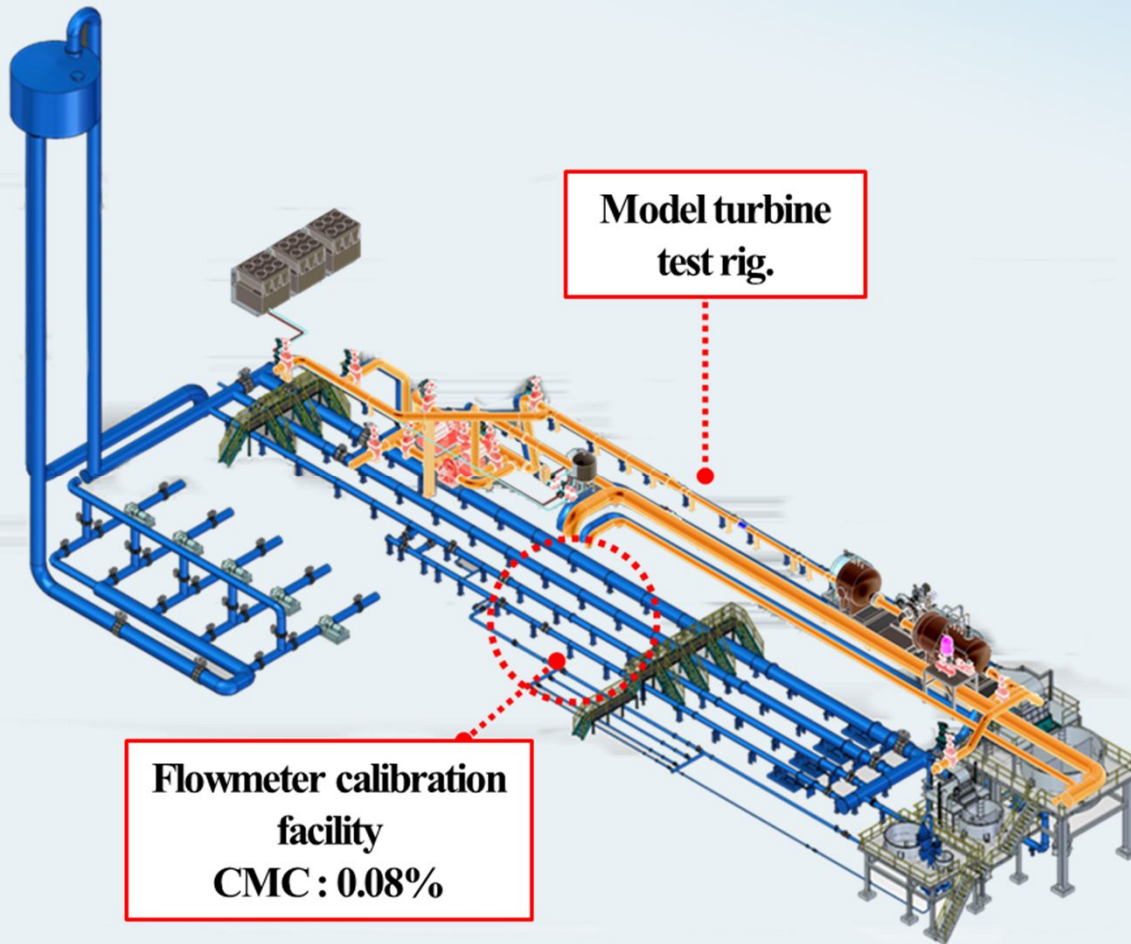
$$\eta_{EU} = 95.68\%$$

※ EU efficiency : **95.68%**



Performance testing equipment for a power converter

Flowmeter Calibration



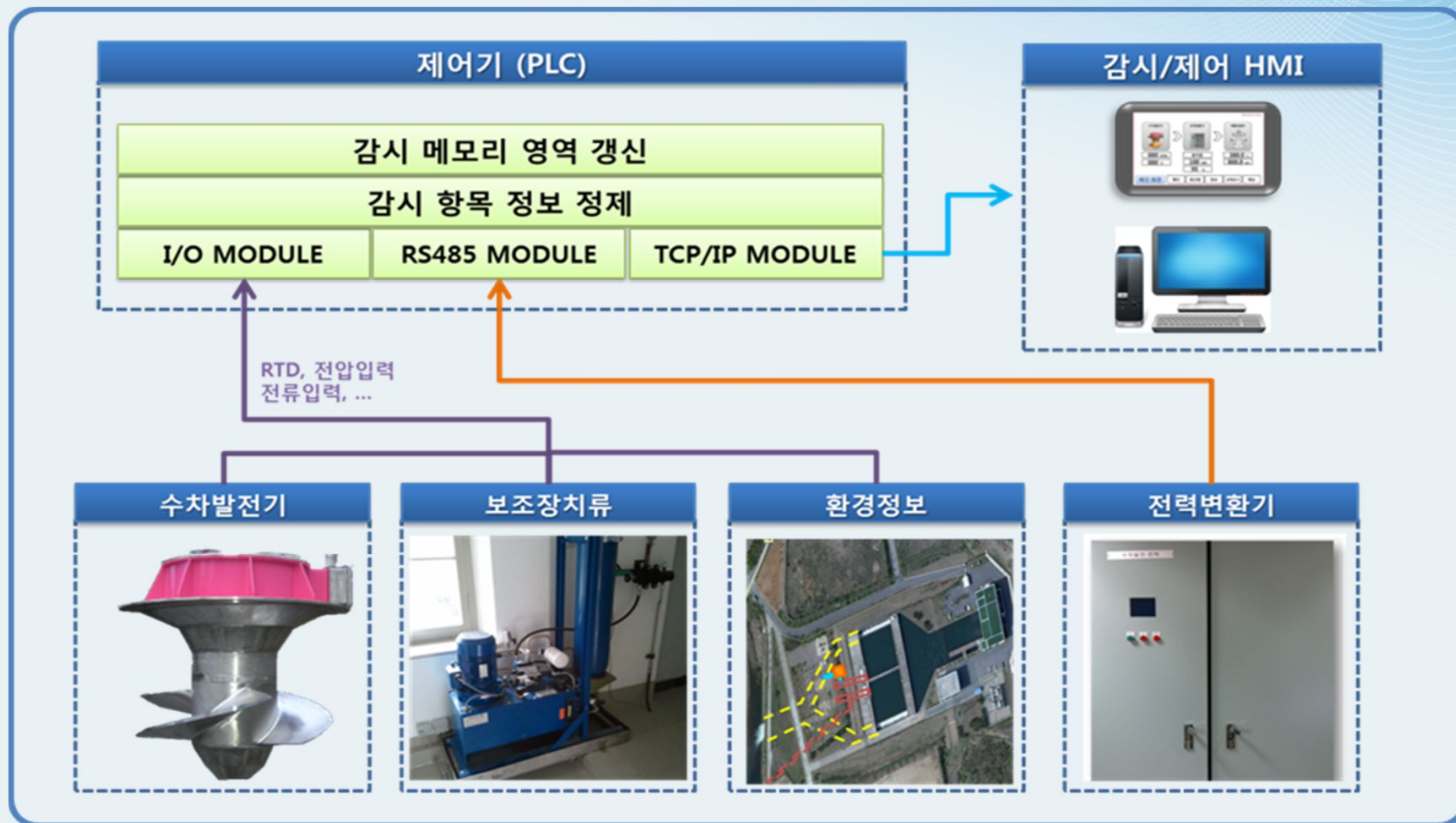
■ 800A electro-magnetic flowmeter

- Calibration of on-site installation flowmeter
- 0.2% accuracy
- 0.04% rel. std. uncertainty with a calibration standard

Construction

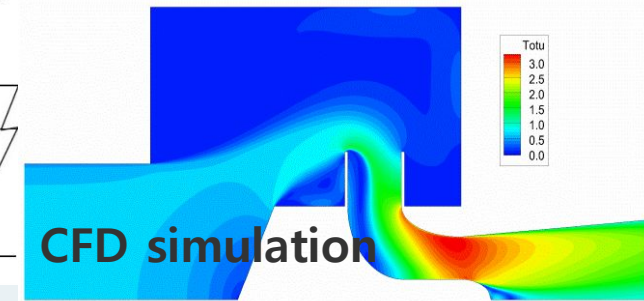
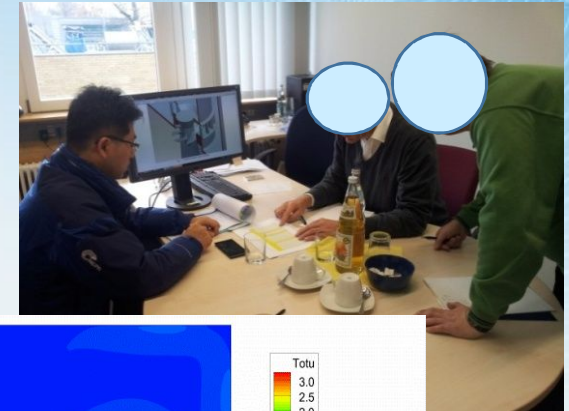
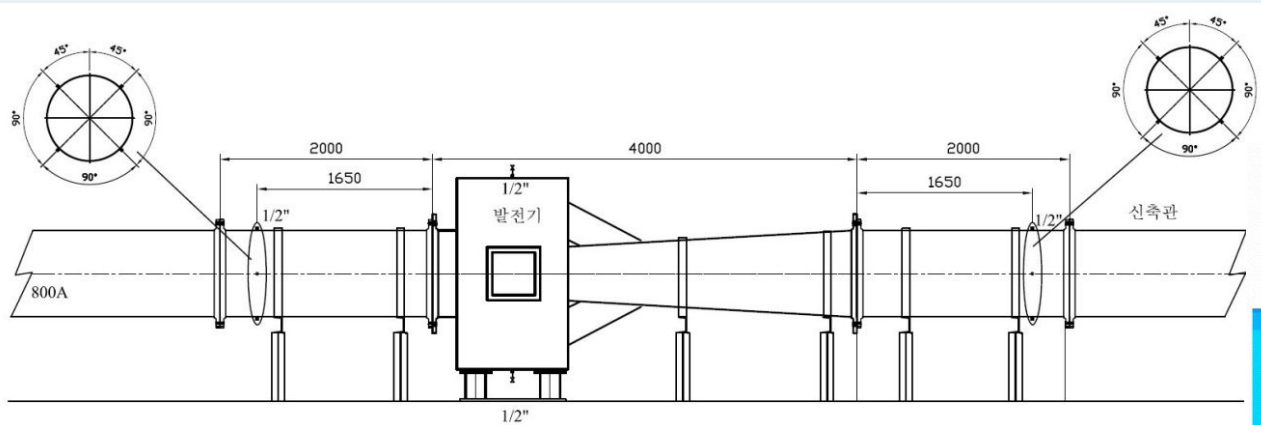


Control System Development

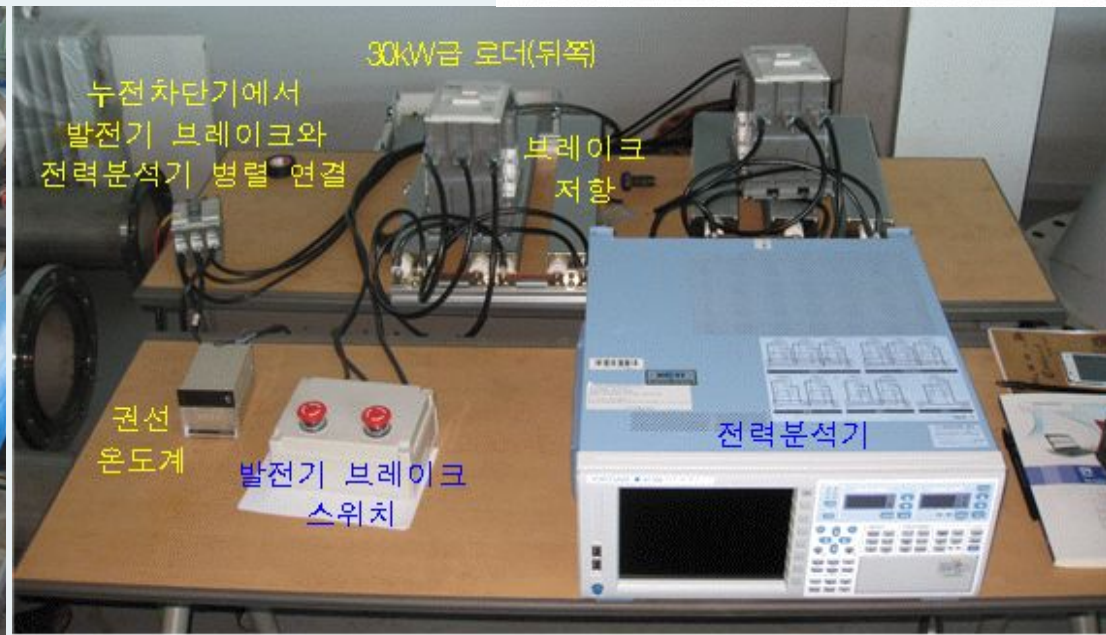


- ✓ Automation
- ✓ Safety control for emergency

Lab. Test for 1st Designed Turbine



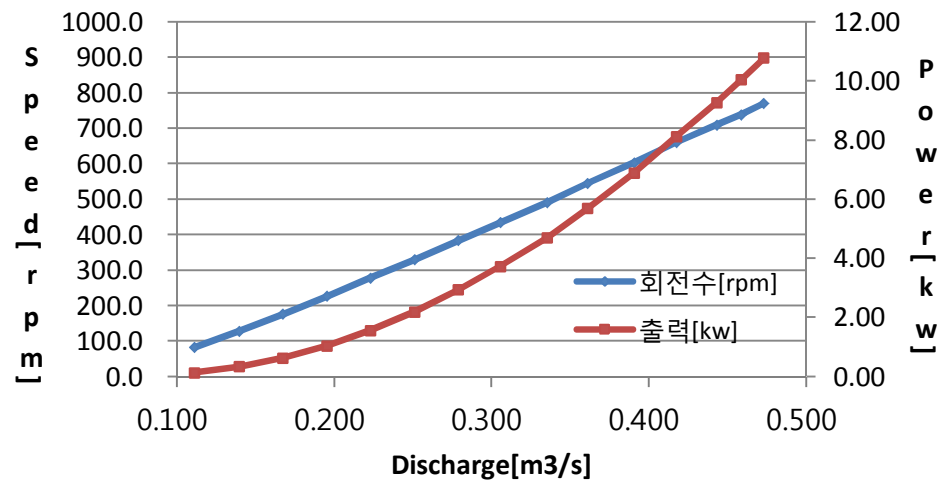
Testing facility



Power analyzer & safety equipment

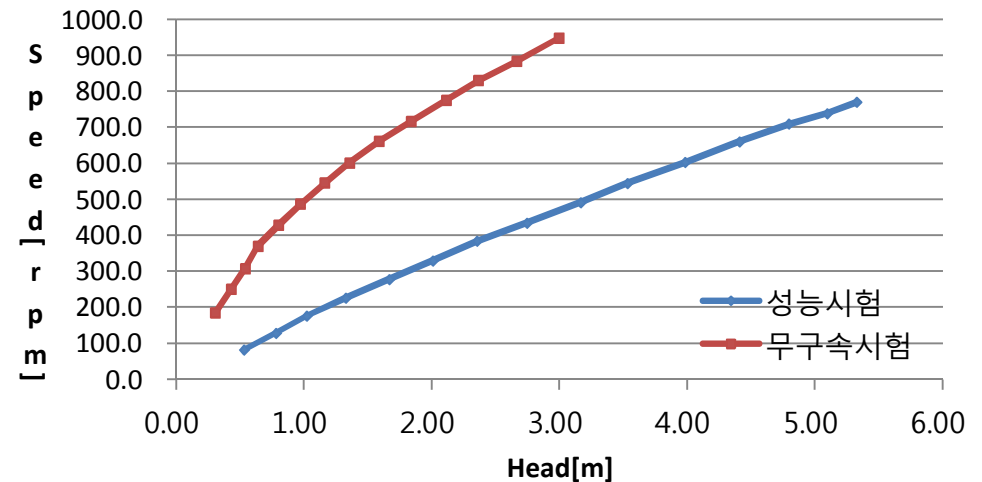
Power output

Discharge (m ³ /s)	Head (m)	Speed (rpm)	Hydraulic Power (kW)	Voltage (V)	Current (A)	Power (kW)
0.279	2.35	384.5	6.41	322.67	5.56	2.94
0.306	2.74	435.3	8.19	364.60	6.25	3.73
0.336	3.16	492.5	10.36	411.47	6.99	4.71
0.361	3.53	545.4	12.45	454.59	7.68	5.70
0.391	3.98	603.5	15.18	502.05	8.43	6.90
0.418	4.41	660.8	17.97	548.11	9.13	8.14
0.443	4.80	710.3	20.75	587.71	9.73	9.29
0.459	5.10	739.2	22.81	611.22	10.14	10.05
0.473	5.33	770.6	24.60	635.62	10.48	10.79

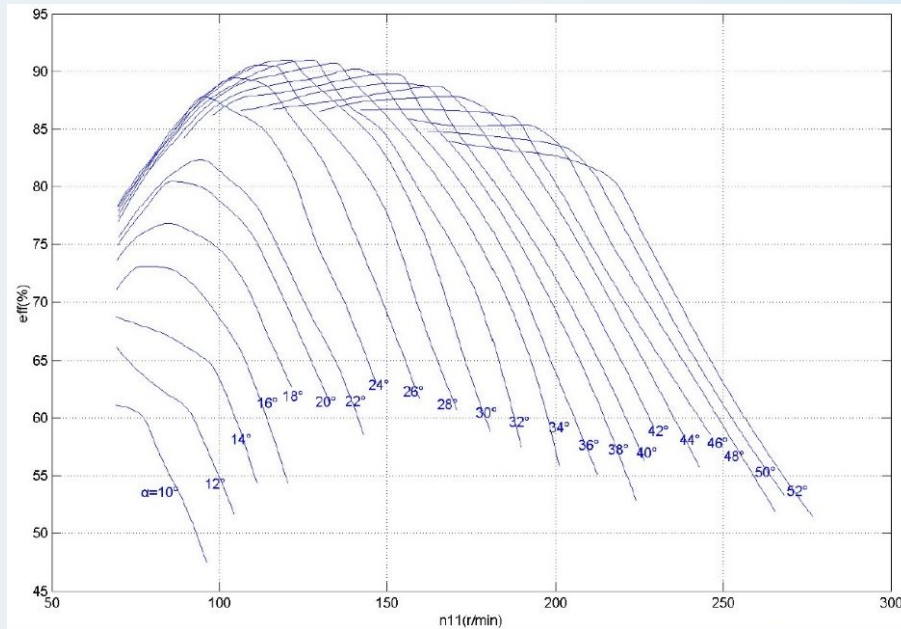


Runaway speed

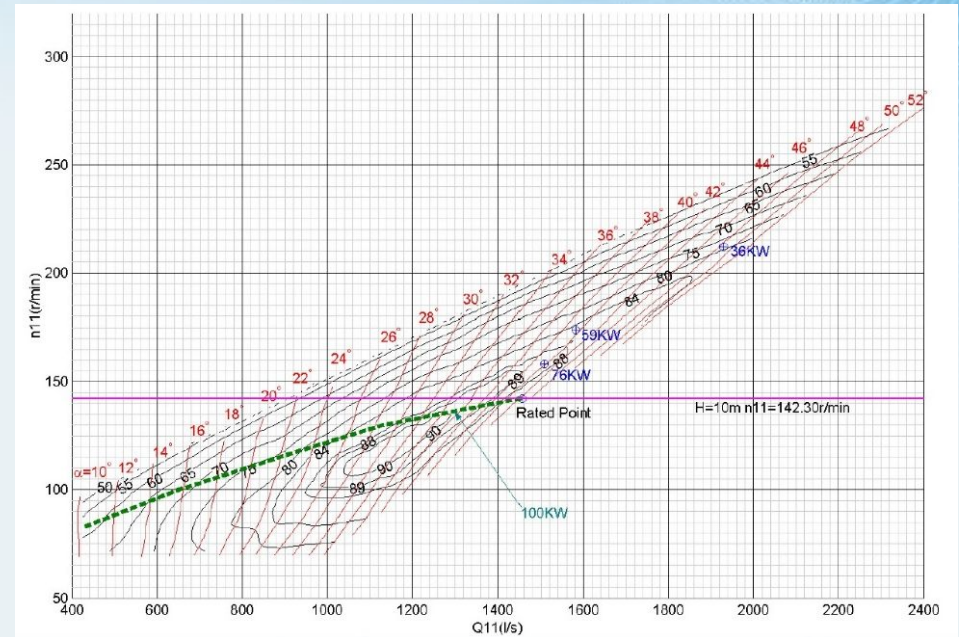
Discharge (m ³ /s)	Head (m)	Speed (rpm)	Hydraulic Power (kW)	Voltage (V)	Current (A)	Power (kW)
0.252	0.97	487.6	2.39	427.00	0.00	0.00
0.280	1.16	546.3	3.18	478.13	0.00	0.00
0.308	1.36	602.7	4.07	527.22	0.00	0.00
0.337	1.59	662.1	5.21	578.60	0.00	0.00
0.363	1.84	717.5	6.51	626.29	0.00	0.00
0.392	2.12	776.3	8.09	676.90	0.00	0.00
0.419	2.37	831.3	9.68	723.65	0.00	0.00
0.445	2.67	884.2	11.59	768.55	0.00	0.00
0.477	3.00	948.9	13.94	823.21	0.00	0.00



Model Testing Results

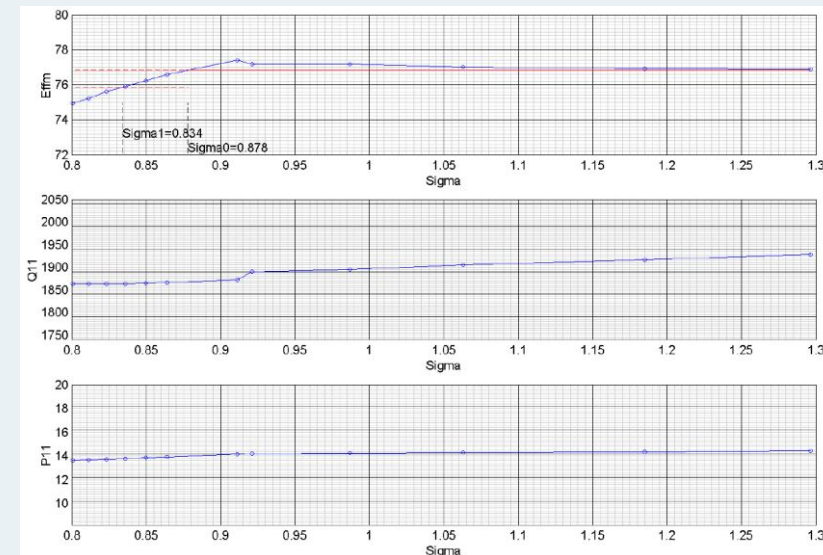


Efficiency curves



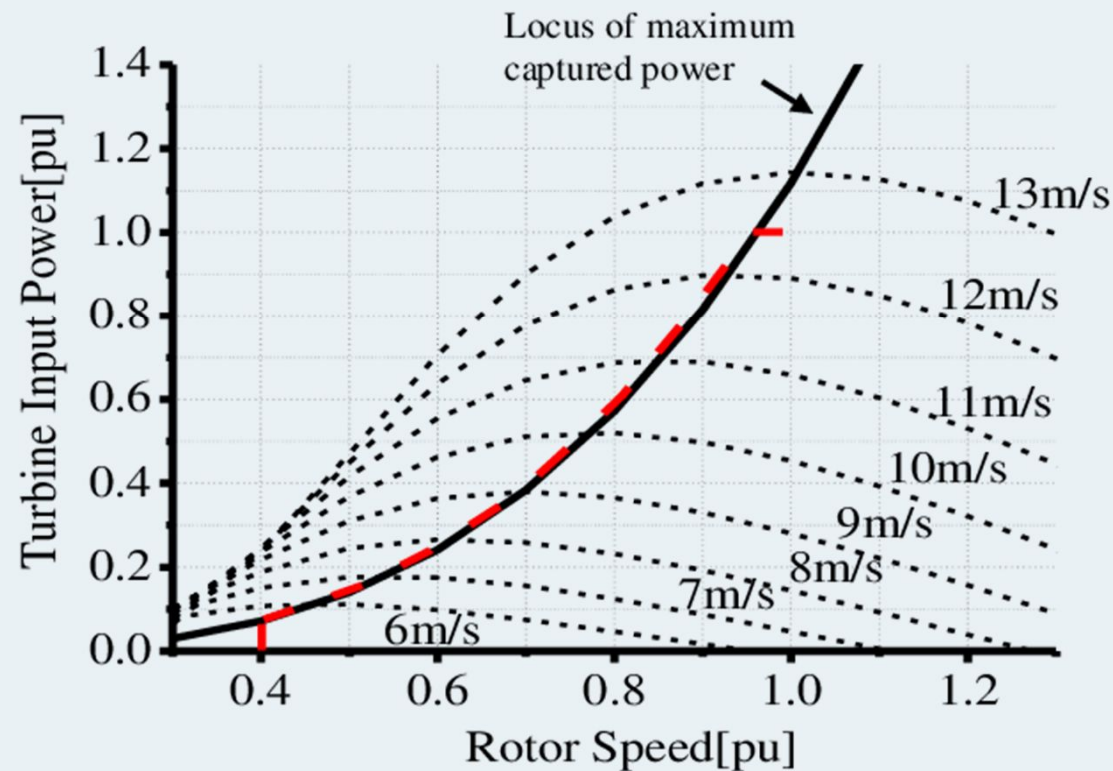
Hill-Chart

- Homologous runner blade
- The others such as a casing, guide vanes, and a draft tube is not homologous.



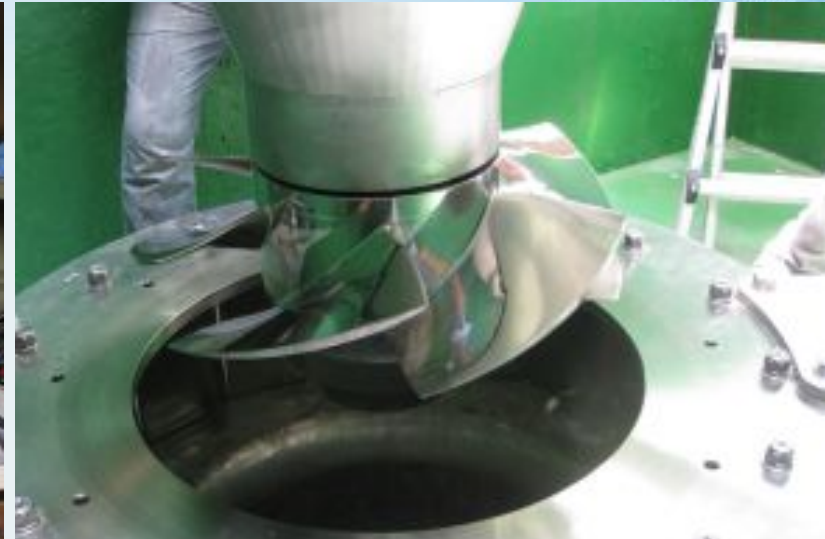
Cavitation Curve

- Max. Power Point Tracking (MPPT)
 - Perturbation & Observation (P&O) MPPT
 - Incremental Conductance MPPT



MPPT for a wind turbine

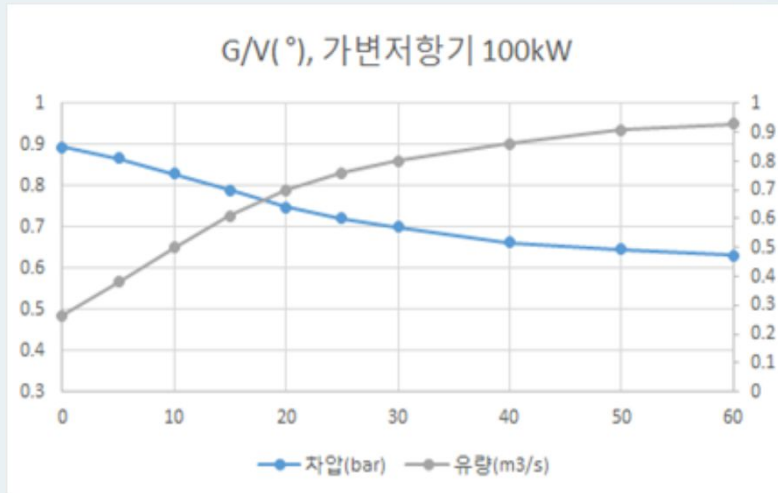
(Hasanien & Muyeen, IET Generation Transmission & Distribution, 2015)



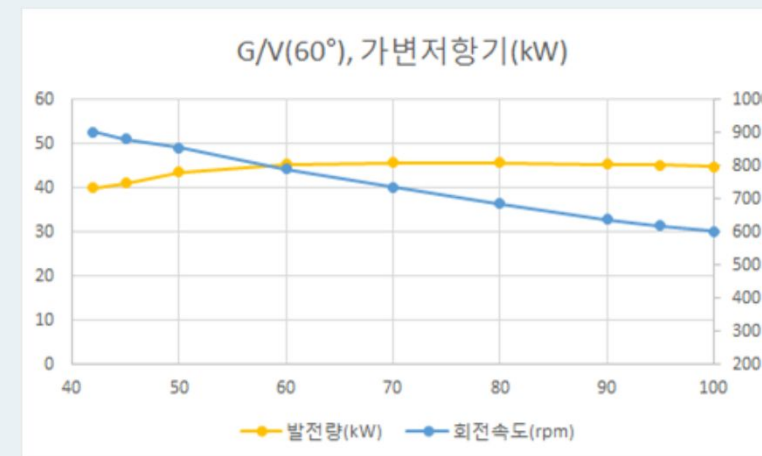
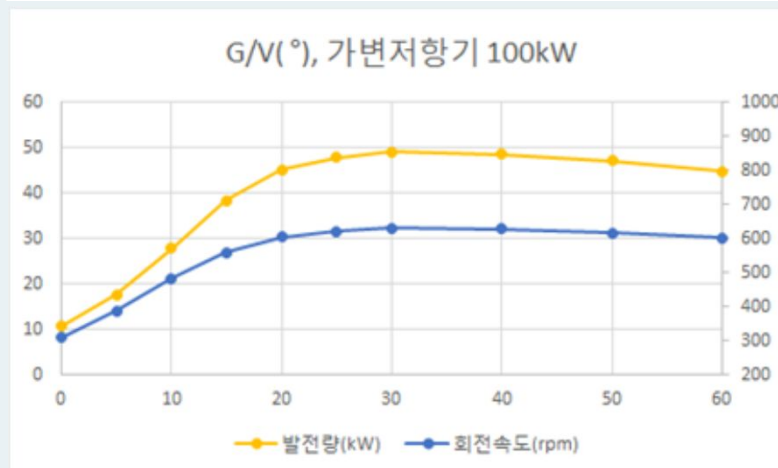
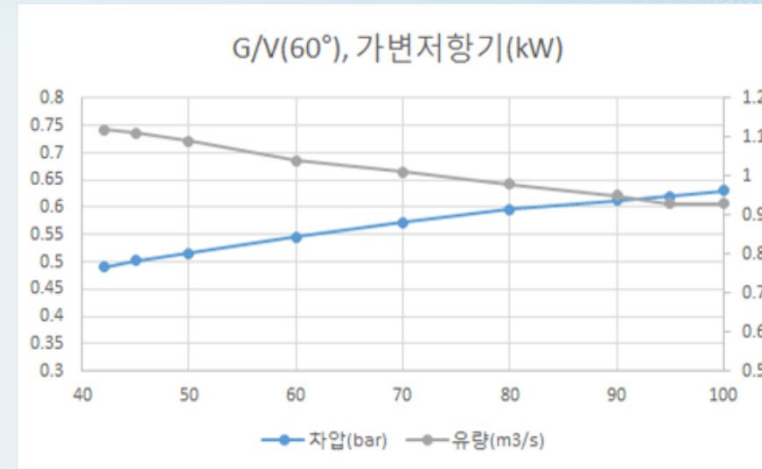
- Preliminary field testing with a large power loader instead of a power converter

Variable Speed Characteristics

GV control



Resistance control

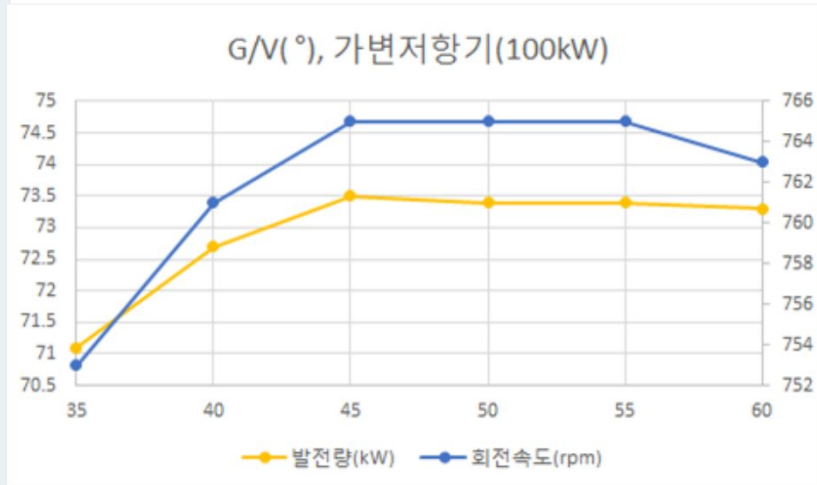
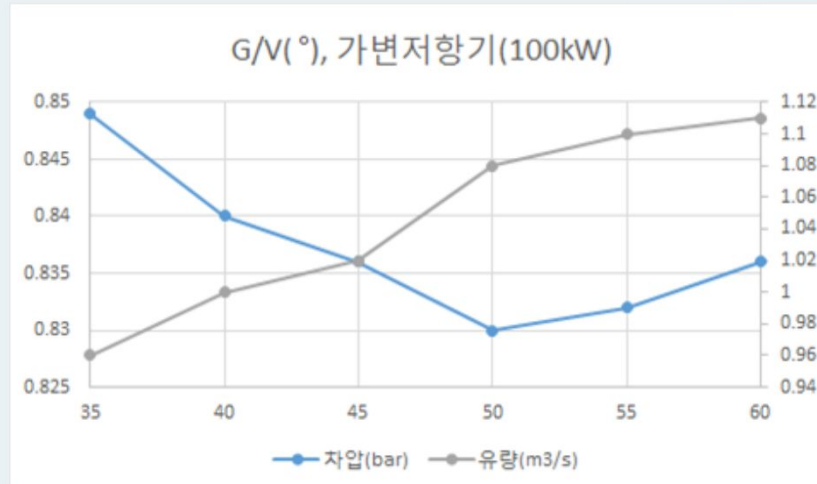


Test results of variable speed characteristics

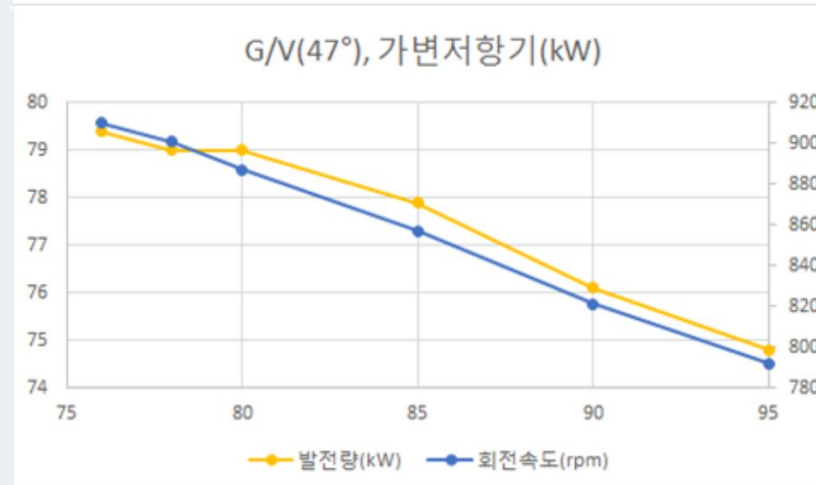
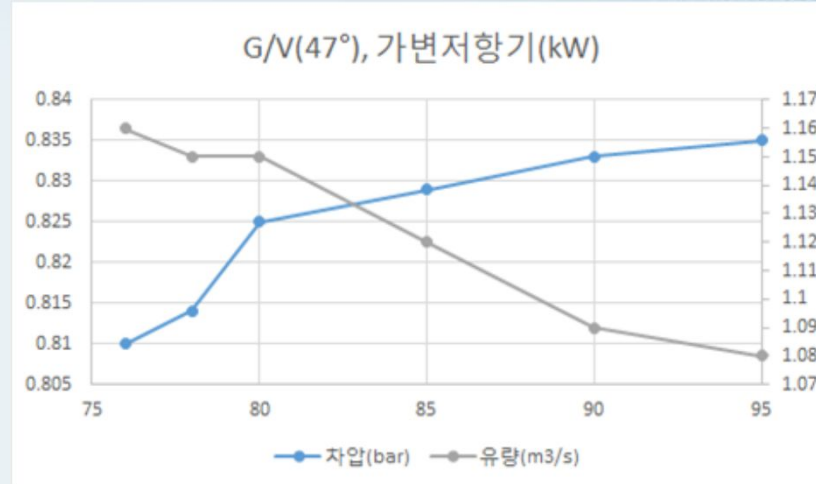
- Discharge rate, dP, power output, rot. speed is varied by GV and resistance control.

Check of Power Output

GV control

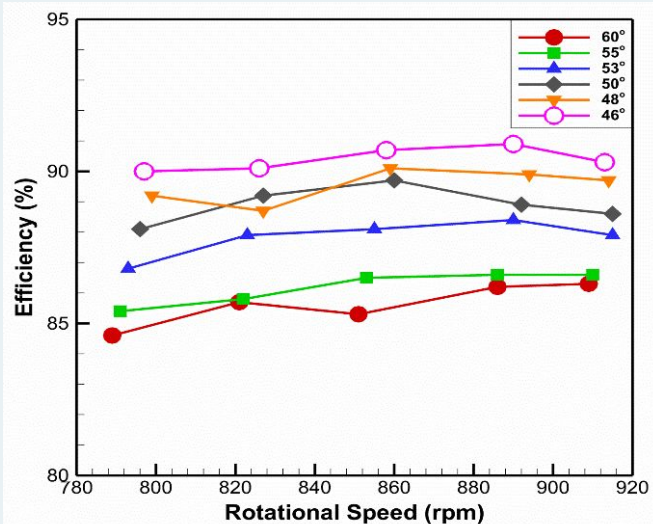


Resistance control

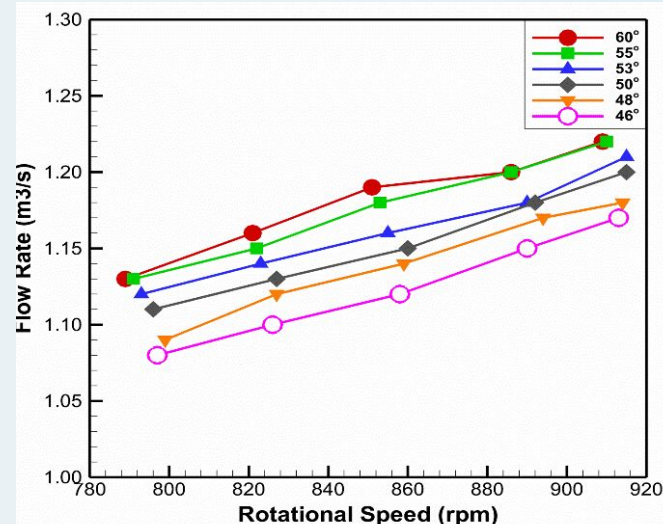


■ Max. power output at GV angle of 47°

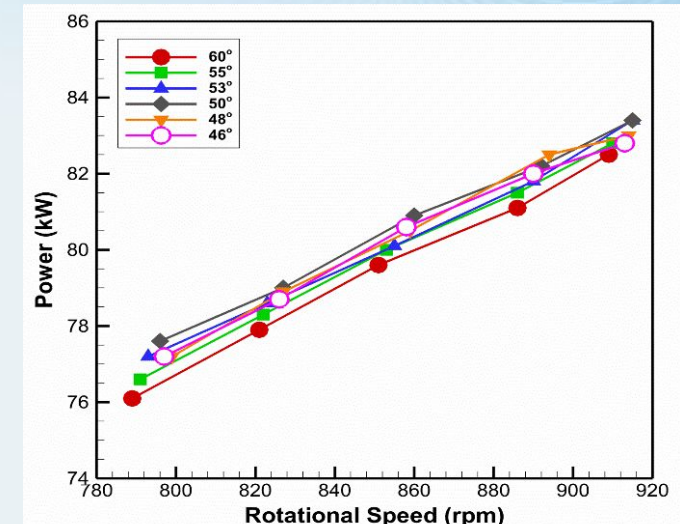
Pre-Test around Rated Speed



Efficiency



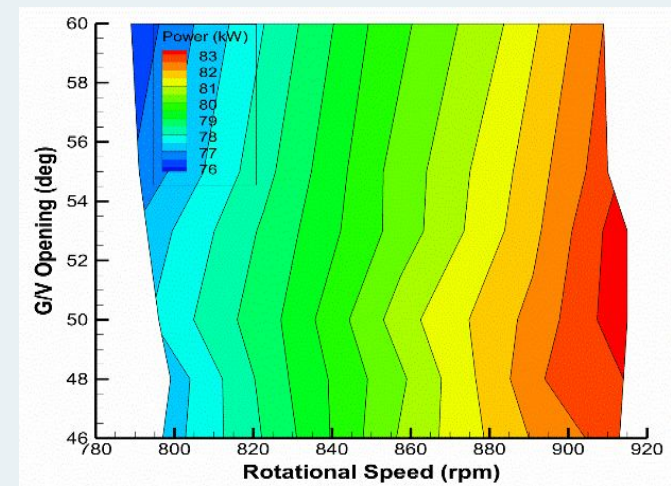
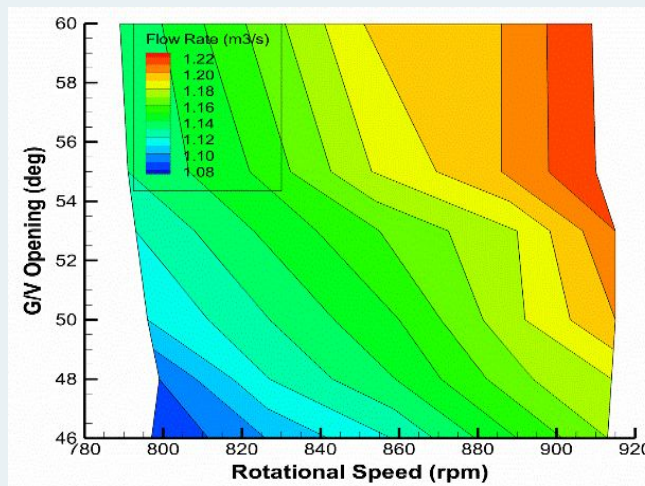
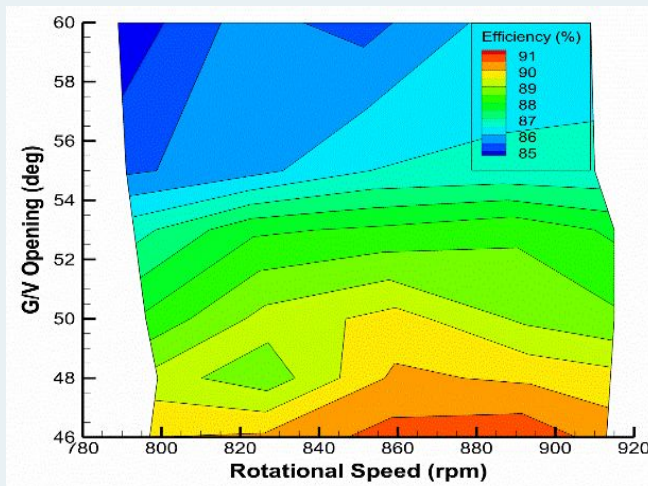
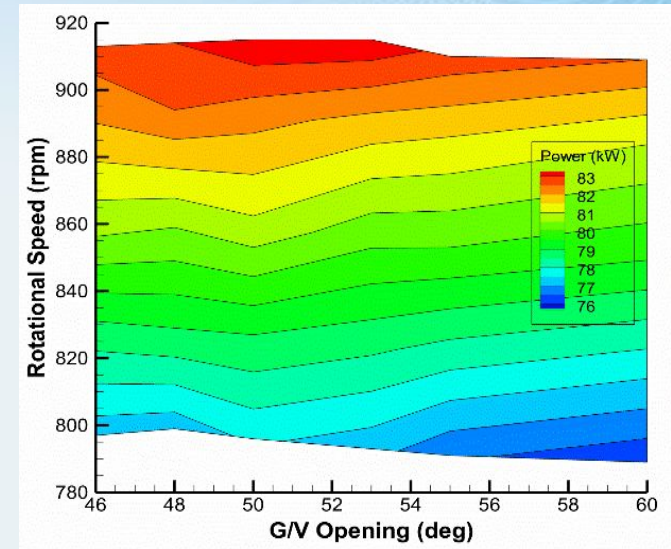
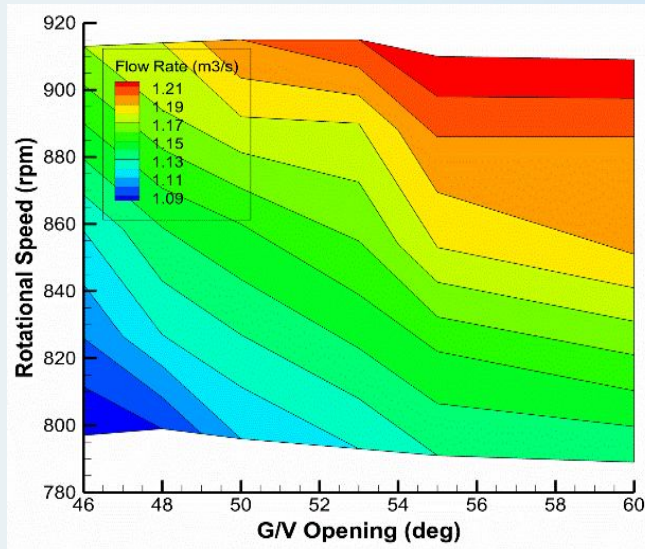
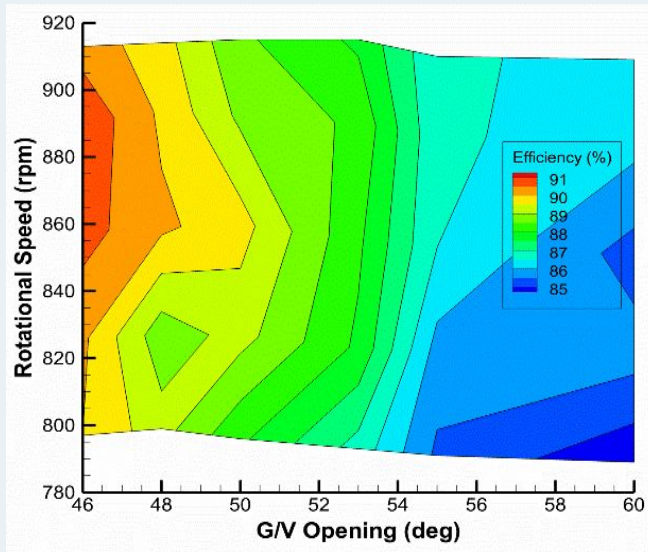
Discharge rate



Power

- High efficiency at low GV angle
- Discharge increase at high GV angle
- Power increases as speed increases
- Max. power at intermediate GV angle of 50° or 53°

Hill Curves for Pre-Test

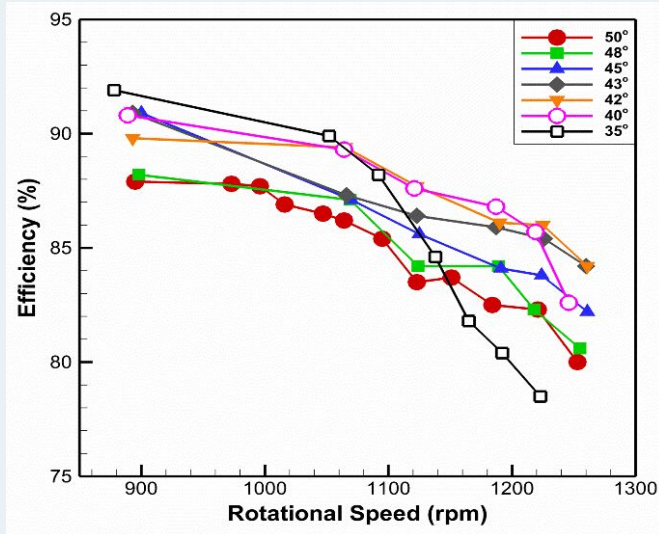


Efficiency

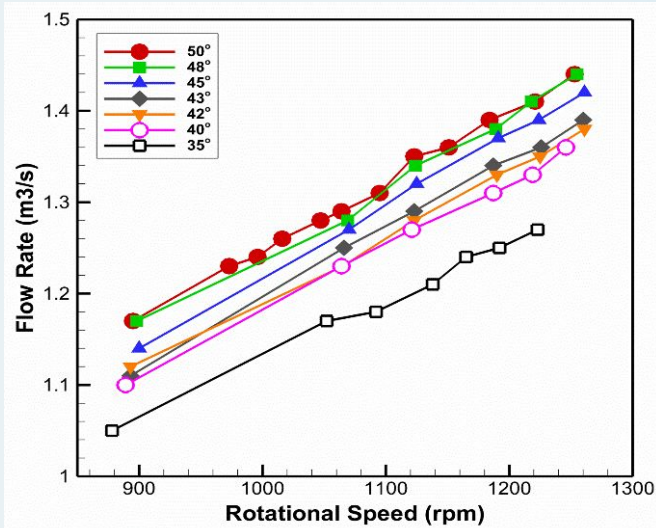
Discharge rate

Power

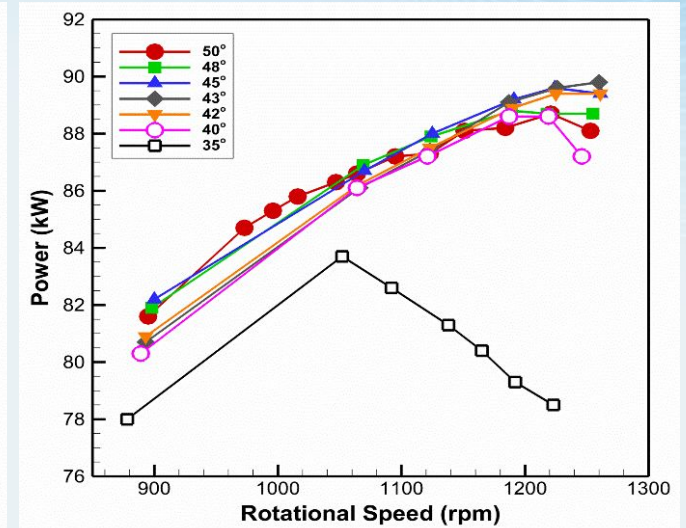
Max. Power Test



Efficiency



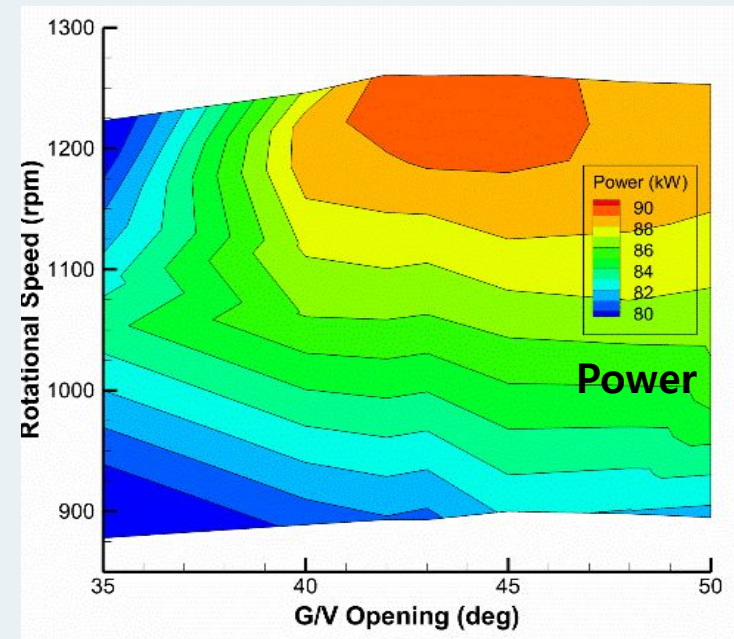
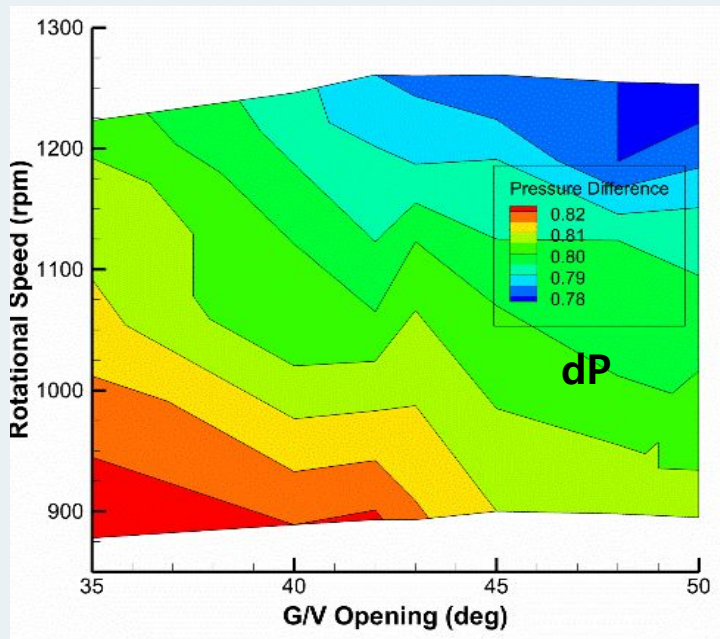
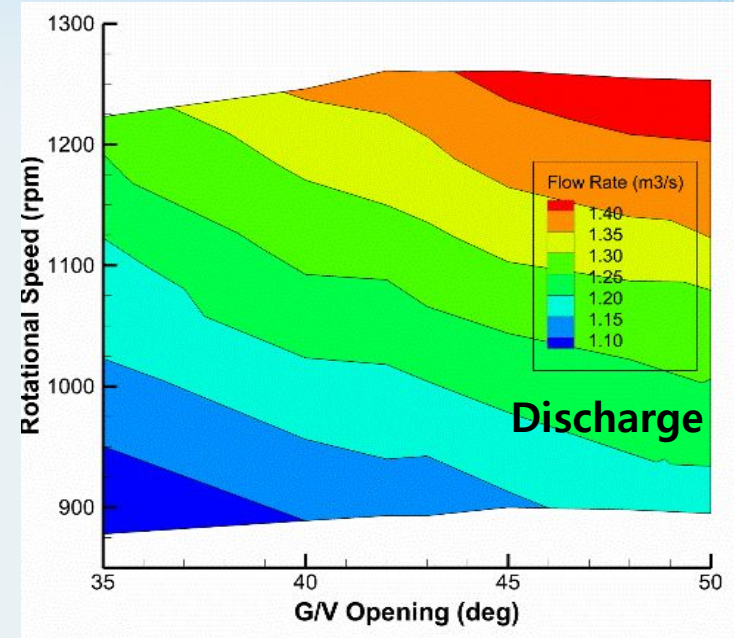
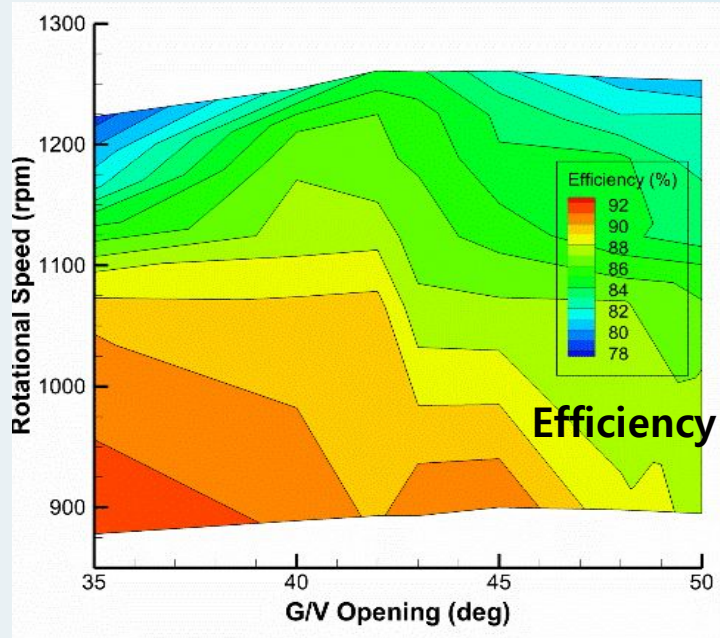
Discharge rate



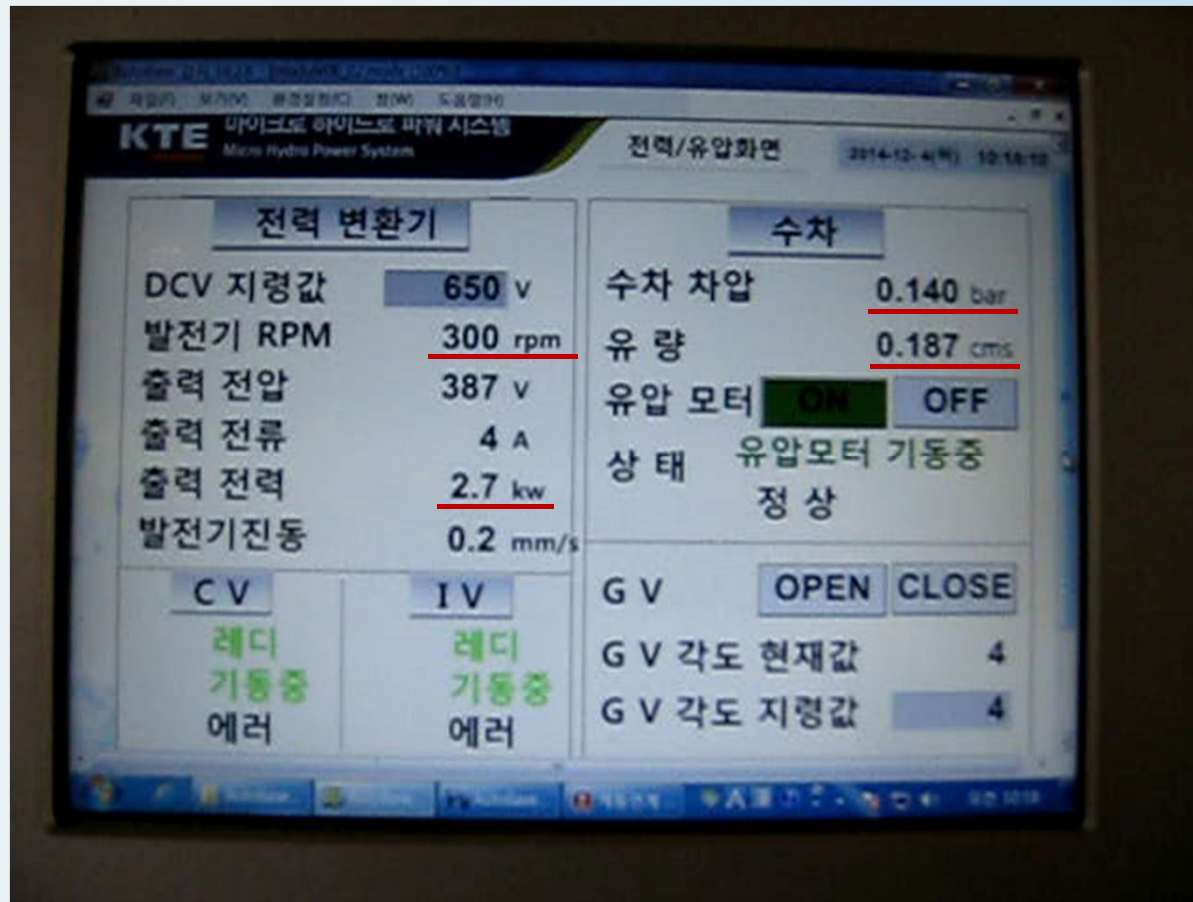
Power

- Over the rated speed to 1,260 rpm
- As the speed increases
 - Efficiency ↓
 - Discharge rate ↑
 - Power has a peak at GV angle of 43°

Narrow-band Hill Curves

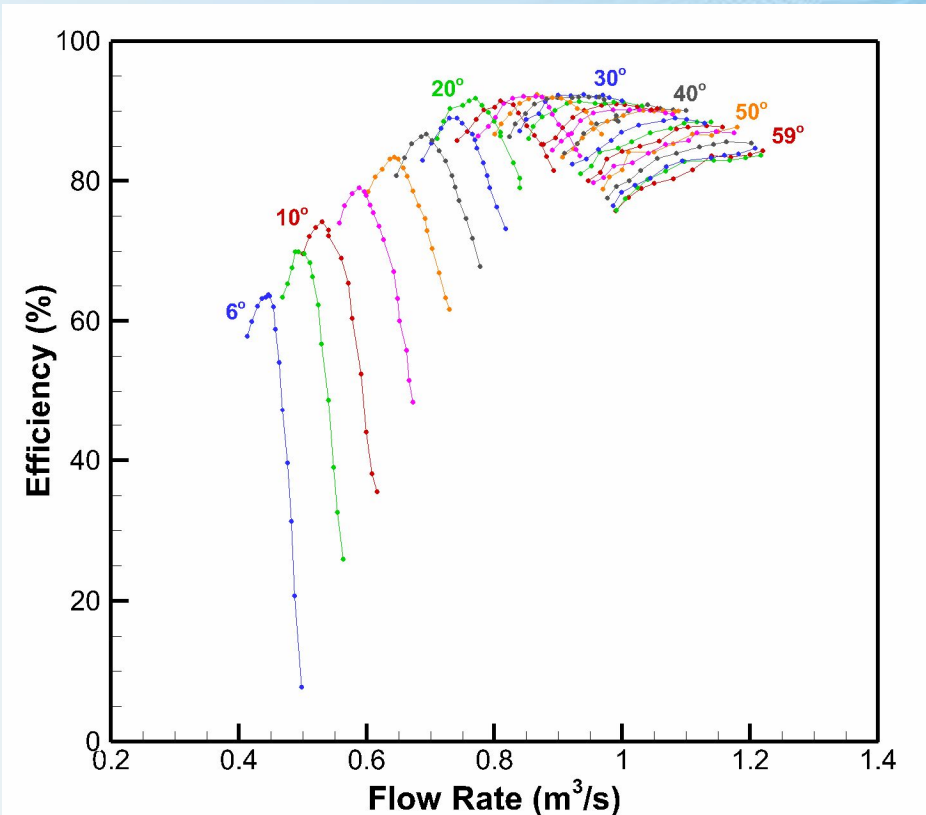
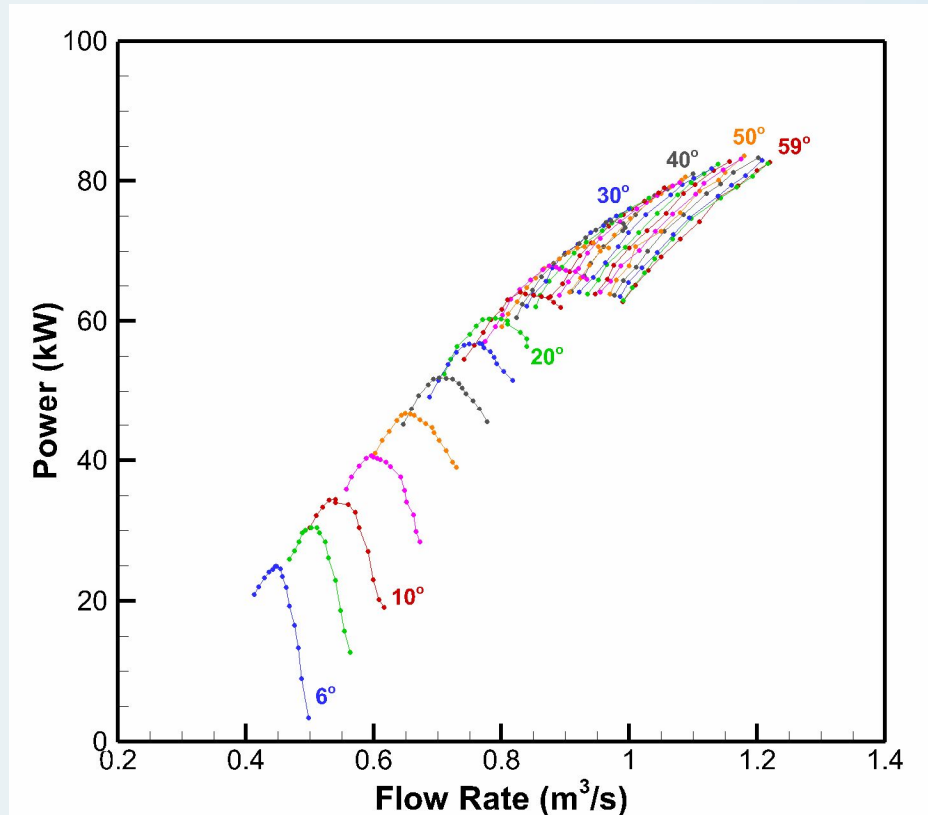


Min. Power Test



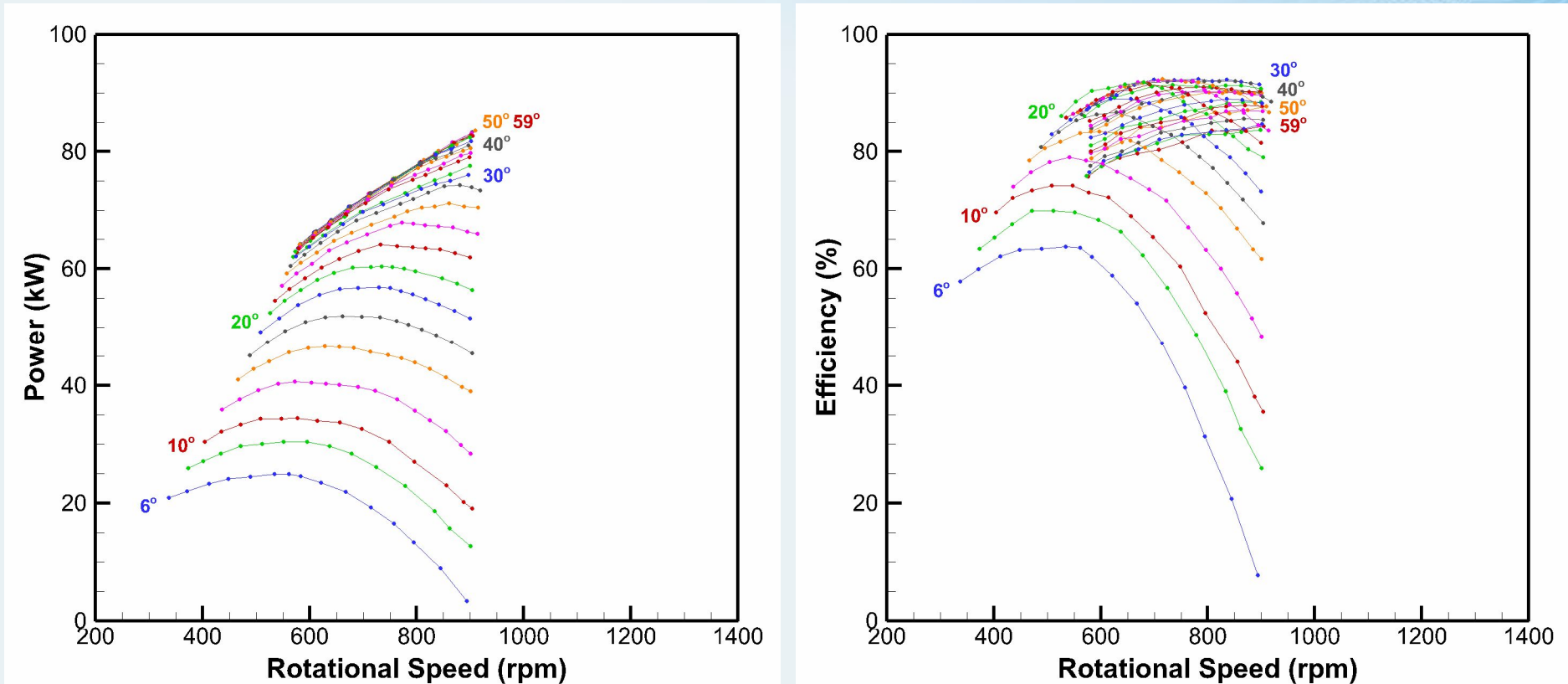
- ❑ Field test with a power converter
- ❑ 2.7 kW at 300rpm, H=1.4m, Q=0.187 m³/s
 - Rated speed of 900 rpm
 - Gross head of 11 m
 - Max. discharge rate of 1.4m³/s

Propeller Curves



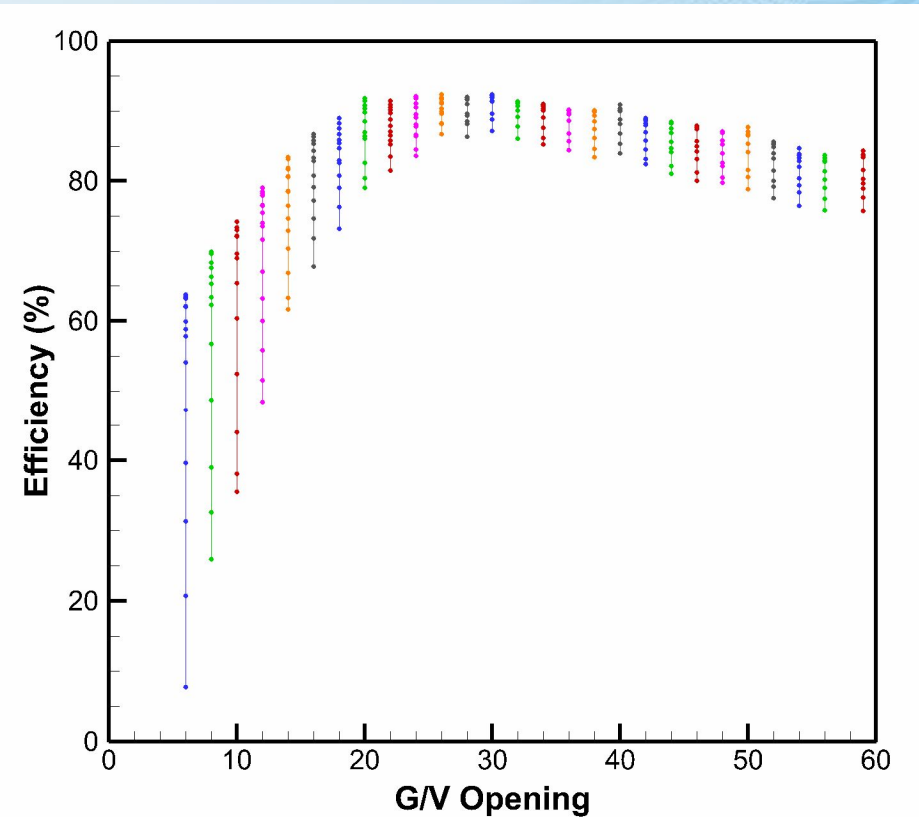
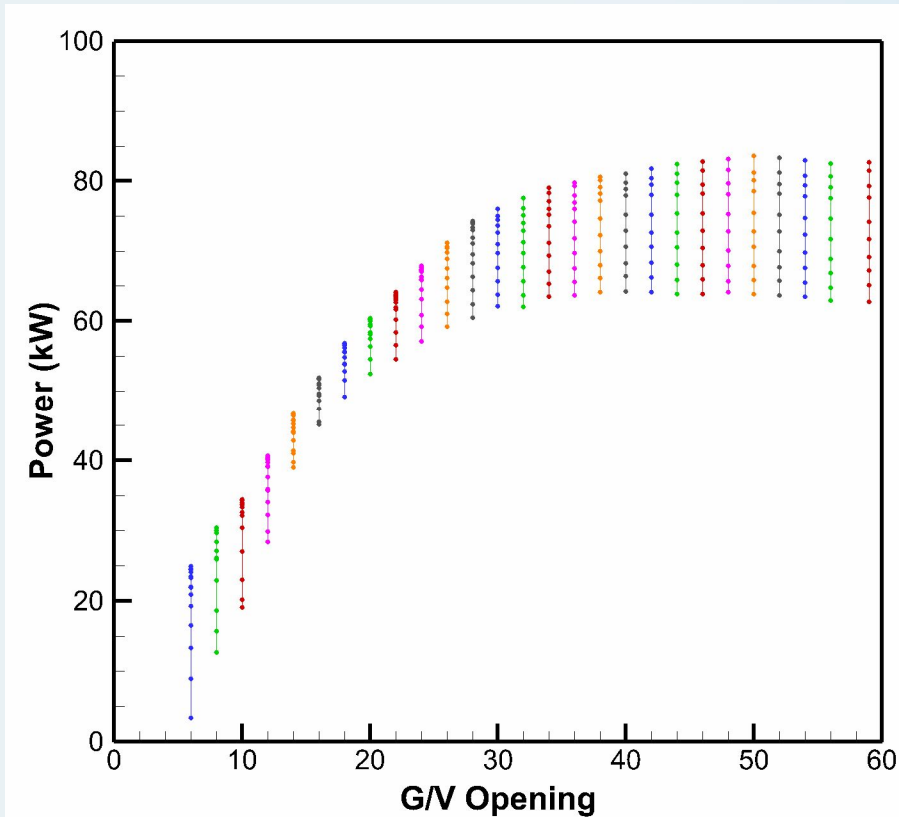
- Propeller curves for every 2° GV angle and rotational speed
- Max. power : GV angle of 50°
- Max. efficiency : GV angle of 30°

Power & Efficiency for the Speed



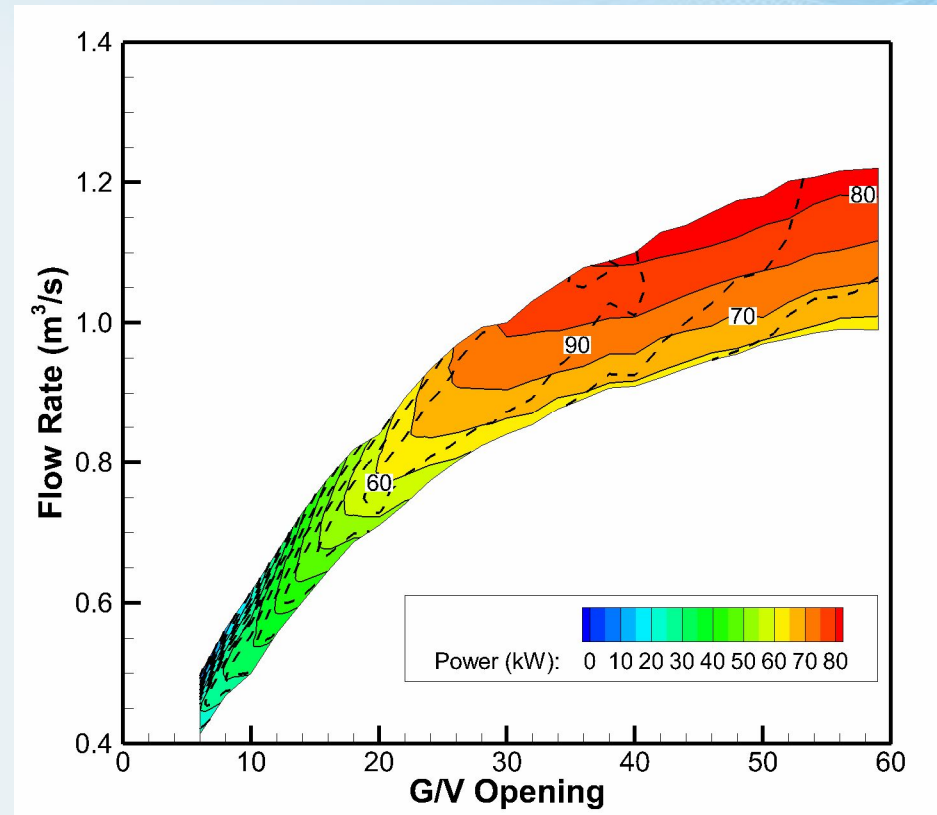
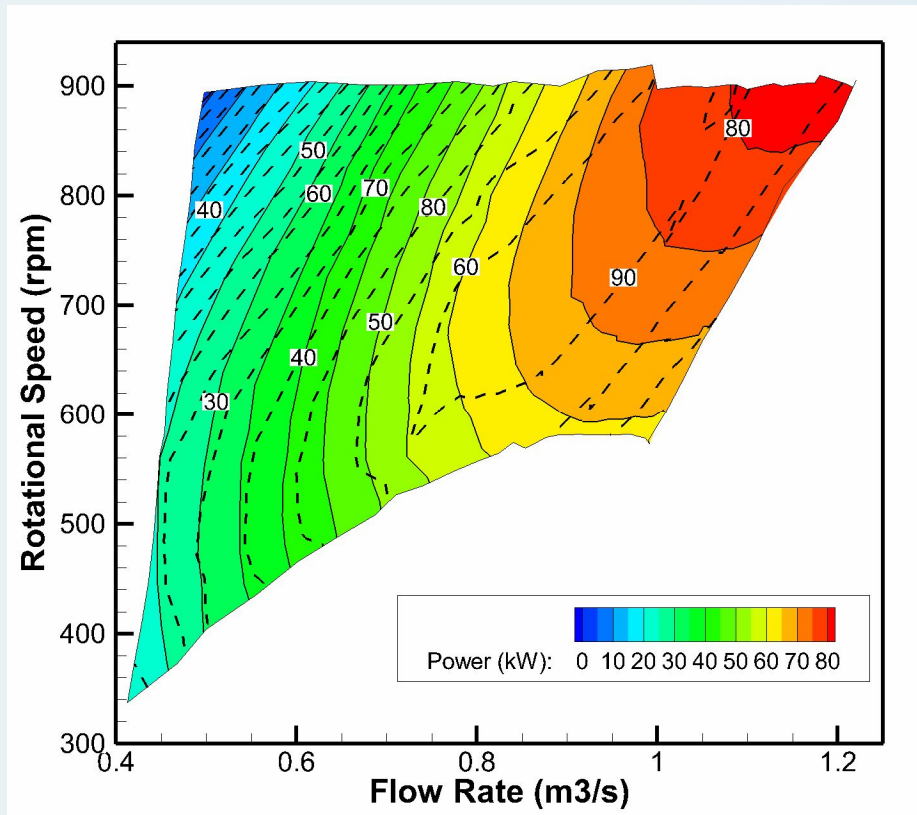
- Optimum rotational speed for GV angles
- Max. power : GV angle of 50°
- Max. efficiency : GV angle of 30°

Power & Efficiency for GV angle



- Operation range for GV angles
- Max. power : GV angle of 50°
- Max. efficiency : GV angle of 30°

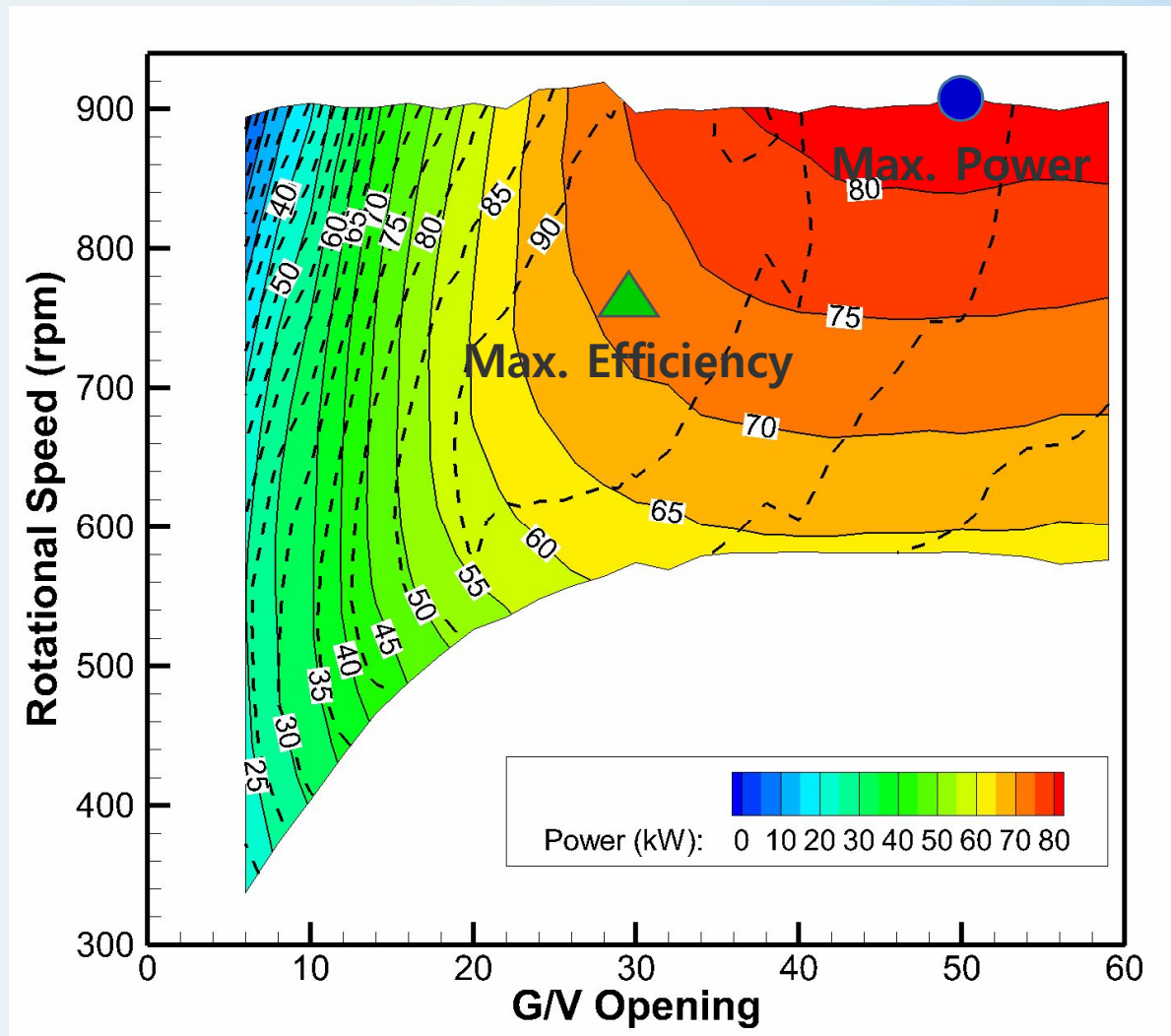
Hill-Curves for Discharge Rate



※ Color: power, dashed: efficiency

■ Hill-Curves for discharge rate, rot. speed and GV angle

Hill-Curves for Control



※ Color: power, dashed: efficiency



Thank you for your attention