# Green-ILC AAA-2014 Report



Advanced Accelerator Association Promoting Science & Technology 2014 AAA Green-ILC Working Group 2015.05.27

English Version

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### 1 Introduction

The total power consumption during operation of the International Linear Collider accelerator (ILC) is 164MW during 500GeV collision energy. Among them, the main linac is accounted for 106MW, where the RF power consumption is 49 %, helium refrigerator is 30% and the remaining 20% or so is the air conditioning, cooling water, lighting, and control racks. Since the main linac constitutes a long linear accelerator which is used repeatedly by the same type of the device, energy-saving and high-efficiency of each device is able to contribute significantly to the overall energy conservation and high-efficiency. Maximizing the efficiency of all equipment used in this ILC, it minimizes the exhausted energy without being converted to the beam, which is inevitable problem in the most advanced accelerators. Furthermore, scientific experiments carried out by using this much power should avoid any inconvenience in daily lives of people regarding to its power supply impact, giving waste heat, noise, etc. An effect to landscape and living environment must also be kept to minimize. Moreover, for the high energy beams after the scientific collision experiments, we should extract its energy from the beam and to re-use its energy so as to be high efficiency accelerator and to be less radioactive waste. Not simply to buy electricity energy itself and not simply to use, but to utilize sustainable renewable energy sources, are the way for not to increase the carbon emission as a view point of the entire earth environment.

As urgent issues of the whole world for this energy problem, many efforts of researchers and companies including the government of each country have been made. Learning from them, and by applying the advanced technology to the ILC accelerator, it is possible to convert the energy to the beam energy with high efficiency, and to minimize the discarding energy to environment. The Technical Group of the Advanced Accelerator Association Promoting Science and Technology formed the Green ILC working group, to initiate the commitment to consider the incorporation of energy-saving technology to the ILC accelerator. Not only by researcher's proposals, but by bringing together the technical capabilities of cutting-edge companies, we propose to incorporate energy-saving technology to an advanced accelerator such as ILC. This is an object of this report to be greening the ILC.

Green-ILC WG Chair: Takayuki Saeki AAA Technology Study Group Chair: Hitoshi Hayano

### 2 AAA Technology Study Group

### **Green-ILC Working Group**

#### **Green-ILC Working Group**

In order to reduce the environment impact, the social impact and operating cost in a large scale advanced accelerator, energy saving and high efficiency component are required to consider their implementation seriously. In the ILC, the implementation of advanced energy-saving technology and high-efficiency equipment from the design stage should be considered. There is a need for the integration and development of utilization technology of renewable energy. For consideration of these technology implementations, we have established a "Green ILC Working Group" in the basis of the technical group. The suggestions from AAA technology studies in the 2014 fiscal year have also been implemented. The activities are summarized in the following table.

Green ILC • WG	Date	Green technology proposer and Technology presenter (affiliation, w/o title)
1-st	2014-2-25	Denis Perret-Gallix(LAP), Junpei Fujimoto(KEK), Atsuto Suzuki(KEK)
2-nd	2014-5-8	Yoshio Kawakami(Toshiba electron tube), Masato Noguchi(Maekawa), Tadashi Fujinawa(Riken), Junichi Honda(Solar power association), Mitsuo Takeda(Kabuki)
3-rd	2014-7-1	Junpei Fujimoto(KEK), Ken Watanabe(KEK), Hiroyuki Nishi(Shinnihon-Kucho), Tadashi Fujinawa(Riken), Denis Perret-Gallix(LAP)
4-th	2014-9-24	Tadashi Fujinawa(Riken), Osamu Takehisa(NTT facilities), Takafumi Shimokouchi(Takenaka), Takayuki Saeki(KEK)
5-th	2014-12-10	Toru Shibagaki(Toshiba), Hajime Sakuma(NEC), Kentaro Otsuki(Tohoku Electric), Denis Perret-Gallix(LAP), Takayuki Saeki(KEK)
6-th	2015-2-18	Kunihito Kikuchi(Fujikura), Naoko Nakamura(Maekawa), Manabu Miyamoto(MHI), Mitsuhiro Yoshida(KEK), Takayuki Saeki(KEK)

When we make broadly classify them by a technical content, energy saving technology is 10 proposals, energy recovery technology 2, storage technology of recovering energy 4, the implementation of renewable energy 8. They are summarized in details in the following table. It should be noted, the energy-saving technologies presented at the 34th Technology Study meeting are also incorporated. As we list the AC power consumption in the ILC accelerator, RF Power is 68.2MW, helium refrigerator is 37.9MW, normal-conducting magnet is 22.4MW, facility equipment is the order of 20.8MW. Reported technologies in the Green-ILC working group are the reliable and promising technology to improve these equipment efficiency.

Technology	Sub-system	Report Title	Presenter	Affiliation	meetin
		(concise)	(w/o title)	(concise)	g
Power saving	RF System	CPD Klystron	Kawakami	Toshiba	G-ILC
		CPD Klystron Test	Watanabe	KEK	G-ILC
		Power Electronics	Yamada	Mitsubishi	Techno
				Electric	logy
					Study
	Cryogenics	Helium compressor	Noguchi	Maekawa	G-ILC
		power saving			
		HTS cryogenics	Nakamura	Maekawa	G-ILC
	Infra-structu	Friction reduction	Nishi	Shin-Nihon	G-ILC
	re	chemicals		Kucho	
		High-voltage	Fujinawa	Riken	G-ILC
		Substation			
		power saving			
		Data center	Takehisa	NTT	G-ILC
		power saving		Facilities	
		YBCO HTS cable	Kikuchi	Fujikura	G-ILC
		Smart Community	Shimokouchi	Takenaka	G-ILC
Energy	Beam Dump	Energy recovery	Fujimoto	KEK	G-ILC
recovery		from beam dump			
		Related Beam	Yoshida	KEK	G-ILC
		experiments			
Energy storage	Energy	Co-generation	Osaki	MHI	Techno
	management				logy
					Study
		Iron energy storage	Hosoyama	KEK	Techno
					logy
					Study

		Power storage	Sakuma	NEC	G-ILC
		Energy management	Miyamoto	MHI	G-ILC
Renewable Energy		Accelerator power saving	Suzuki	KEK	Techno logy Study
		New Energy Power Plants	Fujinawa	Riken	G-ILC
		LN2 Economy	Perret-Gallix	LAP	G-ILC
		Green-ILC	Perret-Gallix	LAP	G-ILC
		Renewable Energies and Environment	Perret-Gallix	LAP	G-ILC
	Solar Power	Solar power generation	Honda	Solar Power Associati on	G-ILC
	Biomass Energy	Biomass power generation	Takeda	Kabuki	G-ILC
	Geo-thermal power	Geothermal power generation	Shibagaki	Toshiba	G-ILC
		Geothermal Power Station	Otuki	Tohoku Electric	G-ILC
	Wind Power	_			
	Marine power				

Greening the ILC by the technology of each company and the efforts of company achievements is the basement of the report. These are easily incorporated to the ILC accelerator during the detailed design stage.

### **3** Green Technology Trends and Application to

### Accelerator in the World

### The Green-ILC (Denis Perret-Gallix, LAP)

























* ilC	Green ILC tasks Governance and Communication		. ILC being the manage a mix	size of a city, is a re	lusions al scale workbench to sources.	develop, maintain ar
A global op	en-research framework between Research, Aca and (Local) Government (Citizens)	demy, Industry	<ul> <li>HEP: a driver an ambitious b</li> </ul>	for innovation: a unic ut rewarding endeav	ue opportunity <mark>to link</mark> pr:	HEP and Energy R&
First time i     A pluri-disc	n the world iplinary R&D dedicated to Energy		One of the needed to	: most important issue: I lay	<mark>Energy</mark> , boost basic energ	y research which is mo
Open to for     Intellectual	eign research organizations and companies Pronerty issues, cross-funding		Raise ILC	and fundamental researc	h public visibility and app	reciation
annoncorda	rieporty asses, a see randing,		Better loc	al appraisal: ILC provide	s rather than consumes e	nergy resources
	Green ILC Communication		<ul> <li>Great saving separate add makes sense.</li> </ul>	n running cost particula tional budget, ILC is a (	rly if RåD/infrastructure very) long term effort, in	es are supported by a vesting in green energi
Towards th	e ILC community: LCWS workshops and other CERN LHC, CER	RN FFC, ESS,	<ul> <li>Better flexib</li> </ul>	ility in ILC operations (I	ess GRID dependence)	
More gener	al Conference on "Power Innovation" for large research/indus	strial infrastructures	<ul> <li>Additional mo</li> </ul>	tivations for the deci	sion makers: ILC goes	beyond basic science
<ul> <li>Toward the</li> </ul>	public and the local citizens		— In Japan:			
Prototype:	http://tinyurl.com/mj8t3o3		<ul> <li>Revitaliza Tohoku, G</li> </ul>	tion of the economics (A lobal cities (Japan Policy	benomics), Re-industriali Council), industry (AAA)	zation after Tsunami ii and internationalizati
	Green ILC Feasibility report by 2014-2015		- Elsewhere: f	wer incentives. But ene	gy is a big and motivating	g issue for everyone
AAA Green ILC 2	5/2/14 Denis Perret-Gallix@in2p3.fr LAPP/IN2P3.CNR5 (France)	50	AAA Green ILC 25/2/14	Denis Perre LAPP/IN25	t-Gallix@in2p3.fr 3.CNRS (France)	
AAA Green ILC 24	Additional slides	50	AAA Green ILC 25/27/4 Renew Energy Source Photocolfaic acover (for households)	able ener Total capacity before PY2011 4.4 GW	- Gollivélinépa fr 3. CNRS (France) COS JAPA Total capacity starting operation in P/2012 1.269 GW	(METI) Total capacity starling operation in FY2013 (a May 31, 2013) 0.279 GW
AAA Green ILC 24	Additional slides	50	AAA Green ILC 25/2/14	able ener Total capacity before Pr2011 4.4 GW	r-GollinéPin2p3.fr 3.cNR5 (Frence) Total capacity starting operation in P12012 1.269 GW 0.706 GW	(METI) Total capacity starting operation in FY2013 (a May 31, 2013) 0.279 GW 0.961 GW
AAA Green TLC 24	Additional slides	50	AAA Green LLC 25/27/4	Donie Perre LAPP/11x2 abble ener Total capacity before Pr2011 4.4 GW 0.9 GW 2.5 GW	<ul> <li>Gollikélinépa fr.</li> <li>ScNRS (Frence)</li> <li>COSS J Dapan</li> <li>Total capacity starting operation in FV2012</li> <li>1.269 GW</li> <li>0.706 GW</li> <li>0.063 GW</li> </ul>	(METI) Total capacity starting operation in P7203 (a Mey 31, 2013) 0.279 GW 0.961 GW 0.002 GW
AAA Green TLC 21	Additional slides	50	AAA Green ILC 25/2/14 KEnergy Source Energy Source Photovoltaic power (for household) Wind power Wind power Small and medium hydropower (LOD kWd mydropower (LOD kWd mydropower (LOD kWd mydropower (LOD kWd mydropower (LOD kWd mydropower (LOD kWd mydropower (LOD kWd	LAPP/21A2 able ener P/2011 4.4 GW 4.4 GW 2.6 GW 2.6 GW 4.4 GW	<ul> <li>- GollinéPin2p Ar</li> <li>- GollinéPin2p Ar</li> <li>- GollinéPin2p Ar</li> <li>- Golge J Japan</li> <li>- Total capacity starting operation in FY2012</li> <li>- 1.269 GW</li> <li>269 GW</li> <li>268 GW</li> <li>068 GW</li> <li>068 GW</li> <li>001 GW</li> </ul>	(METII) Total capacity starting operation in FY2013 (a Mey 31, 2013) 0.279 GW 0.961 GW 0.002 GW 0 GW
AAA Green ILC 21	Additional slides	50	AAA Green LLC 25/27/4	Datis Pere LAPY/2142 able ener rv2011 4.4 GW 4.4 GW 2.6 GW 7 9.4 GW	<ul> <li>Gellinébingp J.fr.</li> <li>3.CNRS (Frence)</li> <li>Cogy Japan</li> <li>Total capacity starting operation in FV2012</li> <li>1.269 GW</li> <li>0.706 GW</li> <li>0.001 GW</li> <li>0.003 GW</li> </ul>	(METI) Total capacity starting operation in 77013 (a Mey 31, 2013) 0.279 GW 0.002 GW 0.002 GW 0 GW
AAA Green ILC 21	Additional slides	50	AAA Green LLC 25/27/4	Date Perce           LAPY/DIA           able ener           7.01al capacity before           P/2011           4.4 GW           0.3 GW           2.6 GW           2.6 GW           2.6 GW           2.3 GW           2.3 GW	- GollinéPin2p3 fr 3.CNR5 (Frence)	(METL)           Total capacity starting operation in PYD13 (a Mey 31, 2013)           0.279 GW           0.961 GW           0.002 GW           0 GW           0 GW           0 GW           0 GW           0 GW
AAA Green TLC 21	Additional slides	50	AAA Green ILC 25/2/14 Kenergy Source Energy Source Photovoltaic sower (for hausehold) Wind power Minal and medium hydropower (lass han 1, kvy) Small and medium hydropower (lass han 1, kvy) Sionass power Geothermal power	Date Perce           LAPP/21A2           Date Construction           Date Construction           Construction           A4.6 W           4.4.6 W           0.9 GW           2.6 GW           7         9.4 GW           020         0.2 GW           2.3 GW         0.5 GW	- GollinéPin2p3 fr 3. CNRS (Frence)	CMETID) Total capacity starting operation in FY2013 (a May 31, 2013) 0.279 GW 0.9561 GW 0.002 GW 0 GW 0 GW 0.038 GW 0 GW





<u>* ilc</u>		Wiki site for Green-ILC intern <u>http://wiki.kek.jp/</u> Space-> Gr	al discussion: een-ILC		 <b>ilc</b>	Thenkyou	
	Anno Carlos Carlos Antonio Antonio Antonio Antonio Antonio Antonio Antonio Antonio Antonio Ant	but  but  but  but  but  but  but  but	www. www. angle. an	La constante de		πατικ γου	
AAA July	y 1st, 2014	Denis Perret-Gallix@in2p3; CNRS/IN2P3LAPP - KEK	fr	13	AAA July 1st, 2014	Denis Perret-Gallix@in2p3.fr CNRS/IN2P3LAPP - KEK	14

#### **Renewable Energies and Environment** (Denis Perret-Gallix, LAP) <u>\* ilc</u> ilc \* ilc International Linear Collider THE **GREEN** ILC **Renewable Energies** Innovation = Leadership x C reativity and Environment Energy for Innovation, Innovation in Energy AAA Green-ILC Dec. 10th, 2014 Denis Perret-Gallix@in2p3.fr LAPP/IN2P3/CNRS - KEK Denis Perret-Gallix®in2p3.fr LAPP/IN2P3/CNRS - KEK 1-ILC Dec. 10th, 2014 <u>\*ilc</u> Lepton colliders "wall plug power" Content • Green-ILC project (a reminder) Lepton Collider Wall Plug Powe epton Colliders Figure of Merit: Juminosity per wall plug prover • Eco-Friendly ILC, a driver for innovation Renewable Energies Update on Liquid Nitrogen Economy" Implementing power plants Wind power Geothermal power Ocean power Power generation on ILC infrastructure Excavated Earth for pumped hydro Green Computing Jean-Pierre Dela SLAC AAA Green-ILC Dec. 10th, 2014 Denis Pernet-Gallix®in2p3.fr LAPP/IN2P3/CNRS - KEK Denis Per

















### 4 Energy Saving Technology of Accelerator Device

Collector Power Depression (CPD) Klystron (Yoshio Kawakami, Toshiba-Electrontube)









### **Operation test of CPD klystron** (Ken Watanabe, KEK)



Niddle ( Vk: ボディとカソード間の電 一定の電位を保持する : ~-90kV ↑ Vk / Vcの割合で効率が改善する 90 kV / 50 kV = 1.8 (元が30%程度の場合、54%まで改善する) マルクス回路等を用いていまで \_(DC 90kV?)昇圧、再利用する。 今回の原理実証試験ではこの方式を取る。出力は、 隣にある別のクライストロンへ入力、ダミーロードとする。 館和運転では、電子のエネルギー分布(速度分布)の観点からw を印加することができない。 結果、非飽和の状態でしか適用でき b:アノード電位 ご−ム電流を制御 15-60kV(カソードから正電位) :エネルギー回収には直接寄与しない。 ない。 CWのクライストロンの稼働に際しては、リニア領域ドライブで出 力を制限での稼働となることが多い。このことがCPD方式の検討 を開始した要因の一つである。 ③6.6kV交流(50Hz)へ変換し既存電源の入力とする方式(詳細検討未だ) 複数のステーションから回収した電力を一か所にまとめて再利用することで、変動は減らせるか? ①VkとVcを直列にする「Power={Vk+Vc}\*Ib」の概念図 クライストロンへのCPD方式の適用(4):③の場合 <u>クライストロンへのCPD方式の適用(4):②の場合</u> 回収した電力を電源ラインのどこに戻すか? 実証試験では、できる限り既存システムと回収電力系を切り離すことを考える。 :電圧変動を経由していたテングの恐れもあるか? 幸い、別の通常のクライストロンをダミーロードとして使用することが、比較的容易に設定できる 変電設備 をい、別の通常のクライムトロンモント 状態である。 :別の電源システム、クライストロンが近くにある。 図の機成を 電力回収装置 DC-ACへの変換装置 受電盤: 3Ф 6.6kV いた実証実験においては、回収電力を別のクライストロンを発き、ロードとする(別のクライストロンをダミーロードとする) 取り出された電力をAC 6.6kVに変換。 ACラインに戻し、再利用する。 以下の場合、水冷の抵抗負荷も準備している。実用の場合には れ、変換し既存電源入力とすることも想定している(未検討)。 IVR(誘導電圧調整器) ł ※複数のステーションから回収した 電力を一か所にまとめて再利用する ことで、変動は減らせるか? \_ 00 ▼ 変圧整流器 ÷ クローバー回路 平滑コンデンサ NNN ヒーター、アノード電源 実証試験の際には、隣の別のクライストロン へ入力する î iutput side)









#### まとめ

・コレクター電位降下型(CPD)クライストロンの原理実証試験の概要について報告した。

動作試験にあたり、放射線、電波漏れといった人体に対して有害なものに対する準備を開始したところである。

・2014年度中の試験開始に向けて、冷却水配管、インターロック配線、制御系の構築などを行っている最中である。

・本試験では、コレクターへ入射された電子ビームから電力回収できるという原理実証 までが試験の範疇である。 電力回収装置を含めたクライストロン電源の設計は、今後検討して行かなければなら ない。

・マルチビームクライストロンへの適用にあたっては、設置に必要な床面積などがかな り増えることが予想される。また、電波温れシールドなどを考慮すると、ウライストロン目 体の設置面積(株領)も多くを要求することになるので、ILCなどの場合、これが許容さ れるかがポイントとなる。 ・CDP部のギャップは0C電圧の耐電圧で決定される。クライストロンの運転周波数には 依存しない。クライストロンの周波数が高くなるほど、温れ出す電磁波の量が多くなる ため、さらなる制約が付くであろうことも予想される。 22

### Power electronics technology for power saving power-supplies (Masaki Yamada, Mitsubishi Electric)











むすび ・パワー素子の損失低減により、機器の性能向上を実現、 特にSiCデバイスの適用により、パワーエレクトロニクス 回路を構成するパワー素子の損失を低減 ・パワー素子の損失低減効果と共に、機器全体を対象と する最適設計により、システム全体の効率改善を実現 ・加速器用途への展開においては、特に充電電源の低 損失・小型化に有効であり、今後適用例が増加するも のと考えられる
<ul> <li>パワー素子の損失低減により、機器の性能向上を実現、 特にSiCデバイスの適用により、パワーエレクトロニクス 回路を構成するパワー素子の損失を低減</li> <li>パワー素子の損失低減効果と共に、機器全体を対象と する最適設計により、システム全体の効率改善を実現</li> <li>加速器用途への展開においては、特に充電電源の低 損失・小型化に有効であり、今後適用例が増加するも のと考えられる</li> </ul>
<ul> <li>パワー素子の損失低減効果と共に、機器全体を対象と する最適設計により、システム全体の効率改善を実現</li> <li>加速器用途への展開においては、特に充電電源の低 損失・小型化に有効であり、今後適用例が増加するも のと考えられる</li> </ul>
<ul> <li>加速器用途への展開においては、特に充電電源の低 損失・小型化に有効であり、今後適用例が増加するも のと考えられる</li> </ul>

#### Power Saving of Large-scaled Helium compressor (Masato Noguchi, Maekawa)

#### Abstract

About one-third of the power consumed by the linear collider is consumed by helium refrigeration equipment. For the purpose of power consumption reduction of helium refrigeration unit, it was examined the combination and optimization of the helium compressor and chemical refrigerator. Cooling the compressor suction gas by an adsorbed refrigerator with a required non-large power consumption, it was confirmed to be effective in power reduction of the entire refrigeration system. It was confirmed that heat source required to drive an adsorption chiller is to be well managed by extracting from lubricating oil system of the high-pressure-stage helium compressor. The study that was modeled on the refrigeration system of the CERN / LHC as a representative of a large refrigeration system, it was confirmed to be about 7% of the power reduction in linear collider. (This document is a report of re-validation based on what was presented at the 24th SOFT: Symposium on Fusion Technology [1].)

#### 1. Introduction

In the linear collider, cryomodules with built-in superconducting accelerating cavities are arranged in many areas to accelerate electrons and positrons. Helium refrigeration system for cooling the cavities in cryomodule will be arranged, as shown in Figure 1, ten large 2K refrigeration station, four small 2K / 4.5K refrigeration station, and seven large refrigeration station [2]. Among the power consumed by the ILC, the power consumed by a helium refrigeration equipment is large and it is 45.81MW. The most of power is consumed in the helium compressor [2]. For this reason, it is easily leading to think about a reduction in power consumption in helium compressor in ILC. However, it can not be expected now more efficiency improvement, since the efficiency improvement has been studied in the long history of the helium refrigeration system development and the helium compressor development.



Figure 1 layout plan of ILC refrigeration unit

In an oil injection screw compressor used in the helium compressor, the suction volume capacity and the shaft power are not changed when the suction gas temperature is changed. As a result, it has been confirmed in a large helium compressor for NIFS / LHD [3,4] that the power consumption per unit weight flow rate will reduce, as the intake gas temperature become low.

On the other hand, when we install a refrigerator for the purpose of cooling the suction gas, the power consumption for the refrigerator is required, so that the benefits of power reduction of the compressor will be cancelled.

Assuming a large helium compressor be applied to the ILC, we investigated the relationship between the temperature and the heat capacity of the waste heat recovered from them. Also, we investigated what type of the chemical refrigerating system which can be driven by the waste heat, and to determine the relationship of the cooling performance and the driving waste heat.

Finally, we made to optimize the power consumption of the helium compressor and chemical refrigerator.

#### 2. Heat balance of oil injection type screw compressor

In the development stage of helium liquefier, reciprocating helium compressor has been the standard. Later, after adopted the oil injection type screw compressor in satellite cooling system of TEVATRON at Fermilab in 1979, for large helium refrigerator system with long-term operation, oil injection type screw compressor has become a global standard.

Features of the oil injection type screw compressor is to inject a large amount of oil during the compression of the helium gas. The temperature of the lubricating oil supply is approximately 313-318K, the temperature of the discharge oil becomes comparatively low temperature (349-365K).

Considering the large helium refrigeration system, such as ILC, refrigeration systems of CERN / LHC is a good reference [5]. As a basis for comparison, we examined a similar model compressor as described above using a Japan-made compressor. The model compressor is shown in Figure 2.

The highest temperature is the discharge side of the high-pressure-stage compressor. The lubricating oil of that side has a lot of heat capacity. For heat recovery from the lubricating oil, a new heat exchanger is necessary. Recovering heat quantity from the heat exchanger is decided from the circulation amount and temperature of the lubricating oil, as shown in Figure 3.

On the other hand, the amount of heat required to add cooling of the helium gas is decided from the amount of circulation and the temperature difference between the gas. The cooling heat from the 310K is shown in Figure 4.



Figure 2 model compressor based on the CERN / LHC specifications.



Figure 3 heat recovery temperature and the amount of recovered heat Figure 4 required heat to add cooling of gas

With reference to Figures 3 and 4, the ratio of the cooling heat amount and the recovery amount of heat required for each heat recovery temperature, COP, can be obtained. When the discharge temperature of the high-pressure-stage compressor is set to 363K, the COP curve are shown in Figure 5. It is good if there is a chemical refrigerating machine which has a higher COP than shown in the curve.



Figure 5 COP which is required in the chemical refrigerating machine

#### 3. Chemical refrigerator characteristics

For the chemical refrigerator not consuming a lot of power to drive, there are absorption chiller and the adsorption chiller. Each of the representative structure are shown in Figure 6 and Figure 7. Also, each of the COP characteristics are shown in Figure 8.

Absorption refrigerating machine with lithium bromide solution as a refrigerant is the most common in the chemical refrigerating machine, and the COP in the drive temperature range is high. To separate the water from the dilute solution, it requires the waste heat of a relatively high temperature ( $\geq$  360K), and seem not suitable for heat recovery applications from the helium compressor.

On the other hand, application of the adsorption chiller that can make the cold water from the lower temperature of the waste heat in recent years has been increasing. Adsorption refrigerating machine consist of two adsorbent layers, a water condenser with a built-in silica gel, and an evaporator, is operated by periodically switching the adsorption layer A / B. In the state in Figure 7, moisture adsorbing layer B is desorbed by the waste heat, and liquefied by the cooling water in the condenser. The condensed water is fed to the evaporator and evaporated in the adsorption effect of the adsorbent layer A, then it becomes low temperature.



Figure 6 Absorption chiller

Figure 7 Adsorption chiller

An overlay to the requirements of Figure 5 with the refrigerator COP in Figure 8 is shown in Figure 9. Absorption refrigerating machine itself has high COP, however, it is not possible to exert the COP required by the system, so it is not suitable. Although the COP of the adsorption chiller is low, operating temperature is low and it has the COP required in this system.



Figure 8 Chemical refrigerator refrigeration efficiency (COP) Figure 9 Comparison of the request COP and the actual performance of the refrigerator

4. study of low temperature cycle of incorporating the adsorption refrigerator compressor suction gas

The compressor system incorporating the adsorption chiller is shown in Figure 10. By installing additional heat exchanger in the lubricating oil system of the high pressure-stage, the recovered heat is sent into the adsorption refrigerator by circulating hot water made in the heat exchanger to the adsorption refrigerator. By sending the cold water produced by the adsorption refrigerator to the newly installed heat exchanger to the gas system, the discharged gas of the low-ptessure-stage compressor and high-pressure-stage compressor is cooled.



Figure 10 new compressor system incorporating the adsorption refrigerator
When the discharge temperature of the high-pressure-stage compressor is set to 363K, as shown in Figure 10, it is possible to obtain the recovered heat of 845kW with given cooling down to 345K. On the other hand, in order to cooled the helium gas of 310K to 280K by water cooling, 124kW at a low-pressure-stage, 267kW at a high-pressure-stage, total of 391kW refrigeration capacity is required. When the hot water temperature is set to 345K, and the cold water temperature is set to 276K in a heat source water of the adsorption chiller, the COP of the adsorption-type refrigerator will be 0.49, cold water of 414kW is able to produce from the input of 845kW. Accordingly, refrigeration capacity of the adsorption refrigerator has exceeded the cooling heat amount necessary for cooling of the gas, it was confirmed to be established as a system.

Incidentally, considering the helium refrigerator side, the temperature of the helium gas fed to the cold box will be down to 280K from 310K. If the temperature of the cold end of the first heat exchanger inside the cold box (here 80K) is not changed before and after the system change, and temperature of the supplying gas is changed to 280K from 310K, the high temperature portion of the heat exchanger becomes unnecessary. As a result, the temperature of the gas returns to the compressor is even down to 270K from 300K. The density of the suction gas of the compressor is increased, it is possible to make more gas flow in the same compressor. Meanwhile, the discharge pressure of the compressor is increased by adding the heat exchanger to the discharge side of the compressor, the power consumption increases.

The compressor performance under these conditions is shown in Table 1. If we use the same compressor, by making inhalation gas temperature drop, the low-pressure-stage gas flow rate (LP) / intermediate gas flow rate (MP) / high-pressure-stage gas flow rate (HP), respectively 790/908/1698 g/s will increase to 870/964/1834 g/s. On the other hand, the power consumption of the low-pressure-stage / high-pressure-stage compressor will also increase from 1190/3080 kW to 1230/3100 kW. Assuming that one can arbitrarily increase or decrease the capacity of the compressor, as a result of translation of these performance criteria of the LP800/MP880 g/s, the total power consumption of the adsorption chiller was confirmed to be reduced to 3965kW from 4252kW, that is 7 %.



Figure 11 new helium refrigeration system incorporating the adsorption refrigerator

1	1	1						
			Normal Temp.	Cold Temp.				
Mass Flow	LP	g/s	790	870				
	MP	g/s	908	964				
	HP	g/s	1,698	1,834				
Shaft Power	LP-MP	kW	1,190	1,230				
	MP-HP	kW	3,080	3,100				
Shaft power converted to LP800/MP880 g/s condition								
	LP-MP	kW	1,205	1,131				
	MP-HP	kW	3,047	2,830				
	Total	kW	4,252	3,961				
Power for Chiller		kŴ	0	4				
Total Power		kW	4,252	3,965 (-7%)				

Table 1 power consumption comparison

### 5. Summary

For the purpose of power consumption reduction in large-scale helium refrigeration system in the ILC, the combination of adsorption chillers was examined.

By the study discussed above, the following results were obtained.

(1) It is possible to construct the heat cycle with the lubricating oil, as a heat source, of the compressor combined with the adsorption refrigerator.

(2) It is possible to reduce power consumption of about 7% by combining an adsorption type refrigerator.

(3) It is possible to reduce the size of the cold box, by lowering the gas temperature.

(4) The present system is self-contained, and can be operated without being affected by the load of the other lines.

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## Development status of High-Tc YBCO superconducting wires (Kunihito Kikuchi, Fujikura)

### 1. Introduction

Superconductivity is a phenomenon in which the electrical resistance of the material is reduced to zero in the lower side of a certain temperature. Although the electrical resistance of the normal metal drops along with the temperature going down, in the superconducting material, the property of the electric resistance becomes zero below a certain temperature (the critical temperature) (Figure 1). It is not necessarily restricted only the temperature in the superconducting state, in practice, under the three critical points of the current (critical current), the temperature (critical temperature), and the magnetic field (critical magnetic field), superconducting state is emerged (Figure 2). Since superconductivity is zero electrical resistance, it is very fascinating material. From the fact that a practical application of high critical temperature superconducting material is expected in recent years, not only to the conventional superconducting equipment, but more wide range of applications are expected.



Superconducting was first discovered in Hg in 1911, it has been found in a variety of metal material (Figure 3). In the 1970s superconducting applications advances in particle science, metal-based superconducting material such as NbTi, Nb<sub>3</sub>Sn, are applied to realize the wire mass production technology at an early stage. And it was established to put a practical use in superconducting applications equipment such as current MRI and NMR. These metal-based superconducting material are necessary to be cooled to cryogenic temperatures of liquid helium temperature (4.2K / -269°C). In the second half of the 1980s, the high temperature superconducting materials that exhibit

superconducting state at the liquid nitrogen temperature  $(77.3 \text{ K} / -196^{\circ} \text{C})$  or even higher were discovered. In addition to attract much attention as the next generation of the superconducting material, many studies have been made. Unlike conventional metal-based superconducting material, the high-temperature superconducting materials are intended to be a copper oxide-based. From the commitment to the wire of the past, practical use of Bi (bismuth) system and Y (yttrium) system of high-temperature superconducting material is expected. Bi-based high-temperature superconducting wire is the first generation because it is mass-produced initially, Y-based high-temperature superconducting wire is referred to as the second-generation high-temperature superconducting wire because it is expected to mass production following the Bi-based. As described below, Fujikura has been conducting research and development of Y-based superconducting wire as a high-temperature superconductor of the second generation for practical use, and it has started the wire supply.



Figure 3 transition history of superconducting material

### 2. Superconductivity research and development of in Fujikura

Starting from the 1970s, with long history of superconductivity research and development in Fujikura, it has been done research and development of metal-based superconducting material wire and magnet, such as NbTi and Nb<sub>3</sub>Sn. Since the discovery of high temperature superconductivity, it is quickly focus on the Y-based high-temperature superconductor, over more than 20 years since the early 1990s, it has been done research and development aimed at the wire of the Y-based high-temperature superconductor. At initial stage of development, making a short wire was the best. Since there was a boost in the wire development and application equipment development by

the national project of the Ministry of Economy, Trade and Industry through the New Energy and Industrial Technology Development Organization (NEDO), wire performance increased yearly, and in 2004 Fujikura succeeded in making the world's first 100m grade wire (Figure 4) [1]. In recent years, it is reached by the level that can be supplied in the production stably of several 100m grade long wire. In 2010, Fujikura starts to supply commercial Y-based electric conductor material manufactured in-house and the wire feed for the various projects to date.

Y-based high-temperature superconducting wire has a structure obtained by laminating a thin film multi-layer (Figure 5), meanwhile, there is a technical problem that superconducting properties can not be obtained when no specific crystal orientation of the superconductive layer is aligned on a metal substrate. Fujikura solved these problems by the fundamental substrate technology that was originally developed, and has been realized the wire performance of world-class [2]. There are two of these fundamental technologies, and one is the IBAD method and the other is PLD method. First, IBAD method stands for Ion Beam Assisted Deposition, a method of forming the intermediate layer. For forming the superconducting layer having uniform crystal orientation, crystal orientation rising required to be aligned at the stage of the intermediate layer. In the IBAD method, a film-forming particles as a raw material of the intermediate layer is fed onto a metal substrate. By irradiating the assist ion beam from a particular angle at the same time, has enabled formation of a uniform intermediate layer of crystal orientation (Figure 6). Next, PLD method stands for Pulsed Laser Deposition, is a method of forming a superconducting layer. Although the PLD method itself is a general technique as a method for forming the thin film, and Fujikura employs a hot-wall type PLD method to elaborate their own ideas in. In the deposition of the superconducting layer, a deposition temperature is very important parameter. In the hot wall type PLD method, by adopting a method of enclosing the film formation area in a hot wall, the film-forming particles are succeeded in stabilizing the deposition on a substrate, and to achieve high crystallinity superconducting layer (Figure 7).



Figure 4 development of Y-based high-temperature superconducting wire in Fujikura



Figure 5 Fujikura Ltd. Y-based structure of the high-temperature superconducting wire (schematic diagram)





Figure 7.1 PLD device schematic



Figure 7.2 superconducting layer film thickness and the critical current in the PLD method

3. High-performance Y-based high-temperature superconducting wire

Y-based superconducting wire of Fujikura has a high critical current and a high critical current uniformity, by using a manufacturing method that was originally developed with the aforementioned feature. Critical current, in 77K, and in the self-magnetic field, is proud of the 500A / cm-wide and the world's top level of performance, has achieved a very uniform critical current distribution also in the longitudinal direction in the several 100m class of long wire (Figure 8). Although longitudinal current flow in conventional copper wire is uniform, it is difficult to get uniform current flow in the Y-based superconducting wire, because of a process of laminating a thin film, it is not easy to obtain a uniform superconducting characteristics in the longitudinal direction. From efforts for wire production over the years, Fujikura has been to improve the critical current and the longitudinal direction of uniformity, at present is being reached to a level that can be supplied to practical use [3].

When a magnetic field is applied to the superconducting material, there is a property that the critical current is reduced. Fujikura have done the evaluation of medium-critical current characteristics for the Y-based superconducting wire, including the area of up to a strong magnetic field and at low temperature, in cooperation with universities and research institutions (Figure 9) [4]. The application equipment to be used in a magnetic field as a superconducting magnet require a high critical current density in a magnetic field, it has started to consider an improvement of the critical current in a magnetic field as a future technological challenges.

600	[									
500										
400	Higher critical current over 500A									
400 Tana	Ic max = 562 A Ic STDV = 6.8 A									
⊇ <sup>300</sup>	lc min = 533 A	Ic Uniformity* = 3.0 %								
200	lc avg. = 550 A	0 A <u>* Ic Uniformity = (Ic avgIc min) / Ic avg.</u>								
100	-									
0	0 100	200	300	400	500	600				
		200	Position [m]	100	000	000				

Figure 8 critical current distribution of Fujikura Ltd. Y-based high-temperature superconducting wire (reference data)



Figure 9 Fujikura Ltd. Y system in a magnetic field critical current characteristics of high-temperature superconducting wire (reference data)

Some of the measured data (3T ~) include the data measured by the Institute for Materials Research, Tohoku University High Field Superconducting Materials Research Center.

### 4. Application of Y-based high-temperature superconducting

The Y-based superconducting wire is not put to practical use yet, in recent years, long wire is able to produce stably, verification demonstration in various projects have been started. The conventional metal-based superconductor had been limited to use in a range of liquid helium temperature, the high temperature superconductor is to exhibit a critical temperature higher than the liquid nitrogen temperature, and further subject to the influence of the magnetic field for the Y-based high-temperature superconductor, it is expected commercialization in both wide area of operating temperature and magnetic field (Figure 10). Strong magnetic field magnet or the like, some of the superconducting equipment, in the future, are expected to further strong magnetic field, especially the Y-based high-temperature superconductor with less susceptible to the influence of the magnetic field, the application is expected in the strong magnetic field superconducting equipment there.



Figure 10 superconducting applications equipment

In addition to research and development of superconducting wire, Fujikura has been done a basic study of the application to the superconducting magnet and power cable. In the evaluation of the small coil is advanced for the superconducting coil, for the first time in the world, we have successfully developed a 5 T large-diameter high-temperature superconducting magnet of the room temperature bore diameter of 20cm in 2012 (Figure 11). This superconducting magnet uses a Y-based superconducting wire 7.2km manufactured in-house (the coil configuration:  $300m \times 24$ layers), and the center magnetic field strength 5T at operating temperatures 24K, a stored energy 426kJ were achieved [5]. For superconducting power cable, by participating in the yttrium-based superconducting power equipment technology development project of the New Energy and Industrial Technology Development Organization (NEDO), we developed a 66kV / 5kA class superconducting power cable in 2013, to verify the AC loss reduction successful (Figure 12). In this project, we constructed the test line by 66kV class superconducting power cable prepared using the Y-based superconducting wire, performs 5kA energized which is largest as a power cable, and to be less 1W/m per one phase was verified. AC loss of less than 1W/m per phase at the 5kA energized, as compared with the working of the power cable (typically 154kV/600MVA class), the transmission loss of less than 1/4 in consideration of the cooling efficiency is estimated [6].





Figure 11 Y system 5 T high-temperature superconducting magnet

Figure 12 66kV/5kA class superconducting power cable

### 5. Summary

Fujikura have continued to research and development aimed at further improving the performance of Y-based superconducting wire. Among the project with aiming the practical use of Y-based high-temperature superconductor rises variety, Fujikura put the emphasis on the reliability of the wire itself, in addition to the performance improvement, also in wire-making that can withstand practical use, in recent years. In addition, to meet the future demand, it has also started consideration of mass production technology, there is not only in the area of traditional research and development, is also ready to enhance the production capacity as a supplier of Y-based superconducting wire. It is passed through a demonstration verification in various applications, to provide a high-performance Y-based superconducting wire which is excellent in reliability, we want to expect to be able to contribute to the realization of a low-carbon and

high-efficiency energy society.

As a part of this report, "superconductivity application infrastructure technology research and development (II)," the Ministry of Economy, Trade and Industry and "yttrium-based superconducting power equipment technology development", National Institute of New Energy and Industrial Technology Development Organization (NEDO) are included for their outcome that was carried out by trustees.

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## Status of High-Tc superconductor cryogenics for large volume, high efficiency and high reliability (Naoko Nakamura, Maekawa)

### 1. Introduction

Adaptation of high-temperature superconducting cable to the ILC, we think useful as energy-saving technology to reduce the loss of ILC power supply. In order to introduce the current situation of high temperature superconducting cable, we report on the NEDO "high-temperature superconducting cable demonstration project", which was operated by connecting high-temperature superconducting cable to the ordinal power system, for the first time in Japan. In particular, the cooling system of high-temperature superconducting cable is an important key-technology, not only for the keeping of the superconducting state, but for the overall system efficiency and reliability improvement. In this paper, we will introduce the state of the art technology, such as developed refrigeration and cooling system in this project.

2. Outline of the NEDO "high-temperature superconducting cable demonstration project." [1], [2]

In NEDO project "high-temperature superconducting cable demonstration project", the system and the performance, operation, reliability, and maintainability of the system components were investigated, a high-temperature superconducting cable system to withstand the continuous automatic operation in the power system was build, and it was carried out to demonstrate an operation in the power system of more than one year. In parallel with the above demonstration, a large-capacity, high efficiency and reliability of high-performance refrigerator has been developed with considering the practical use of future high temperature superconducting cables. It should be noted that this project is the first project in Japan, which was operated a high-temperature superconducting cable by connecting to the power system.

Study of the impact of high temperature superconducting cable in the power system has been done by TEPCO. Study of the design, production and installation of the high-temperature superconducting cable have been done by Sumitomo Electric. Study of the design, production, and installation of the cooling system as well as development of high-performance refrigerator have been done by Maekawa Seisakusho. They were carried out respectively. The project was started from fiscal 2007. The design, manufacture, and a single verification test were done for the high-temperature superconducting cable and the cooling system. The power system interconnection test in October 2012 was carried out for continuous operation for more than one year, and in December 2013, the study was completed.

High-temperature superconducting cable that was used in this project was a three-core batch type cable with a rated 66kV, DI-BCCO of 200MVA, the length was about 240m. Considering the adaptation to the future of urban power cable laying situation in urban areas, the use of the joint, the cable bends and underground part were provided. In the Asahi substation, where the line is to step down the voltage from 154kV to 66kV, the part of the 66kV bus line was replaced to the high-temperature superconducting cable. Photos of the high-temperature superconducting cable used in this project is shown in Figure 1.



Figure 1 photo of high-temperature superconducting cable

3. cooling system used in the demonstration and its challenges [3]

The cooling system used in this project is the close circulation device. It is composed of refrigerators, circulation pump, and a reservoir tank. The sub cooled liquid nitrogen refrigerant (hereinafter, LN2) were used. LN2 that are sent by the circulation pump performs circulation cooling of the high temperature superconducting cable after cooled in the refrigerator. Flow of the cooling system and the installation situation are shown in Figure 2 and Figure 3.

Selection was made for a refrigerator type by the results to date, and it was also decided the number of refrigerator by the heat loss of the high-temperature superconducting cable system. In the cooling system, six of 1kW@77K Stirling refrigerator were used, and made them in three parallel  $\times 2$  units, considering pressure loss in the heat exchanger, the temperature controllability, and backup during the fault. Two centrifugal circulation pump were placed in parallel. In addition, one refrigerator one and one circulation pump is in the spare, they were automatically activating in the event of a fault. The volume of the reservoir tank was 1000L, considering of the volume change due to temperature change of LN2 in the high-temperature superconducting cable. Furthermore, it is necessary to maintain the pressure more than 0.2 MPaG in LN2 system for keeping electrical insulation of high-temperature superconducting cable, it was installed 3 types of pressure control device including the spare unit into the reservoir tank.

As described above, a circulation cooling of high-temperature superconducting cable using LN2 of sub-cooled state was performed in this project, but the operating temperature of LN2 was controlled to  $69\pm1K$  (standard value) at the inlet temperature of the high temperature superconducting cable, considering the critical temperature of the superconducting material, LN2 temperature rise at the time of trouble such as a short circuit, and temperature margin. Specifically, the operation number control was performed in order to control the temperature by matching the variation in heat loss of the high-temperature superconducting cable between seasons and in a day. Control of operation number of the refrigerator is a commonly used method, even with cold water chiller refrigerator for pipe-tunnel cooling of underground cables, maintenance concept on the power plants are considered.



Figure 2 flow of high-temperature superconducting cable cooling system



Figure 3 photos of the high-temperature superconducting cable cooling system

Current through the high-temperature superconducting cable in the demonstration, temperature of LN2, pressure, and flow rate are shown in Figure 4. The demonstration test, which was lasted 1 year or more, was completed successfully without any big trouble. During this time, not stopping the circulation cooling may be considered as a major achievement. In addition, by the temperature control of the refrigerator, by the pressure control in the reservoir tank, sub cooled state of LN2 was kept, and even possible to achieve a stable long-term circulation cooling. Furthermore, even it was performed several times of the refrigerator replacement work during demonstration, LN2 circulation state was stable, no obstruction of LN2 circulation by ice or so, maintaining the LN2 circulation operation, so, it was able to establish a working techniques to replace disconnected the equipment only individually.



Figure 4 test results of the demonstration

While operation of high-temperature superconducting cable has verified without problems in the power system, however, for practical use, it has become clear that there are a number of challenges. Examples of the resulting problems are described below.

In this cooling system, the six refrigerator were connected with vacuum insulation piping, and further, the bypass line for the refrigerators for maintenance were installed. Therefore, increasing the number of valves of vacuum insulation pipes and bypass, their loss became comparable to the refrigerating capacity of one refrigerator in the cooling system. In order to increase the overall efficiency of the high-temperature superconducting cable system, improvement of the refrigerator efficiency, reducing the loss of the high-temperature superconducting cable, and reducing heat losses in the cooling system, are required. large capacity of the refrigerator which has reducing the effect of heat loss of the cooling system, is thought to contribute to the high efficiency of the entire superconducting cable system.

In this project, the power consumption of the cooling system required to cool the high-temperature superconducting cable is defined as the cooling system COP. In the cooling system used for the verification test, the efficiency has been unquestioned, however, in order to give the operational benefits of future high-temperature superconducting cable, it has to be a COP of 0.1. However, as the results of this verification test, the cooling system COP was approximately 0.04.

Lowering of the refrigerating capacity of the refrigerator started after the start of three months during verification test, sequential performance degradation was seen in the six refrigerator. In order to maintain the refrigerating capacity, 1-2 times of evacuation and the overhaul of the refrigerator by manufacturers were performed monthly. When we use it in a power system, the reliability of the cooling system and longer maintenance intervals of the device are also important. Therefore, it is necessary to develop a refrigerator of long maintenance intervals.

Considering above results, a large capacity, high efficiency, high reliability of the Brayton refrigerator has been developed and introduced in the next section.

### 4. Development of high-performance refrigerator [4]

In terms of the aim of practical application of high-temperature superconducting cable, since a large-capacity, high efficiency and high reliability refrigerator was essential, from February 2011, in parallel with the demonstration test at Asahi substation, development of a high performance refrigerator was performed in this project. Considering the loss of high-temperature superconducting cable during practical application, required single refrigerator capacity was assumed as  $5 \sim 20$ kW, this time target refrigerator capacity was set to 5kW which was 5-6 times the capacity of the current Stirling refrigerator. Furthermore, the loss of the cable system is required to be reduced by 50% over than ordinal cables, in order to achieve this, the goal COP of the cooling system was 0.1. Also, considering the practical use, maintenance intervals of the refrigerator is also an important evaluation items, and 30,000 hours, which were general industrial refrigerator equivalent, were targeted in this project.

To achieve the development goals above, reversed Brayton cycle was adopted in the refrigerating cycle. Reverse Brayton cycle is a refrigeration cycle consisting of insulating process and isobaric process, it is a gas cycle, but, it is the heat pump radiating heat out of the system. The basic system flow and photographs of Brayton refrigerator that was developed in this project are shown in Figure 5 and Figure 6. In adiabatic compression process, considering the refrigerator efficiently become better for plus work from the outside isothermally, and considering the proper pressure ratio of the compressor, the refrigerator employs the three-stage compression. In addition, the turbo type compressor and expander were adopted in order to maximize the characteristics of the reverse Brayton cycle. In addition, in order to be the cooling system COP to 0.1, the design value of the adiabatic efficiency of the turbo compressor-expander was set to 0.8.

Considering refrigerator efficiency, the shape of the rotor blades, a motor specification, and the economical efficiency, first-stage and second-stage turbo compressor, and, the third-stage turbo compressor and turbo expander, are integrated. By integration of the turbo compressor and turbo expander of the third stage, power generated by the expander is consumed for a part of the power for driving the third-stage compressor, which contributes to the efficiency improvement of the refrigerator. The refrigerant of the refrigerator, the helium gas and neon gas has a potential, since it is required to be a low boiling point. In turbo machine, as the molecular weight of the working fluid is small, it become high rotation and tend to be compact, because much high difficulty of the manufacturing as to be compact as described above, we adopt the neon gas refrigerant in this development. Since the rotational speed of the rotary machine in the case of using the neon gas refrigerant becomes  $40,000 \sim 70,000$ rpm high speed rotation, the bearings were used non-contact oil-free bearings. It realizes the increase of

maintenance intervals by using non-contact oil-free bearings, and increased the reliability of the refrigerator. This horizontal type compressor with the pressure sealed structure placed the rotor blades in both ends around a built-in motor. Structure of three-stage compressor and the expander were also similar, but it had the vertical structure for disposing the expander side in the cold box.

This refrigerator consists of, a turbo compressor and an expander, first-stage and second-stage integrated turbo compressor, expander-integrated third-stage turbo compressor, cold recuperator heat exchanger for utilizing the cold heat generated in the expander, LN2 heat exchanger that performs heat exchange between LN2 and neon, and the water heat exchanger for dissipating the heat of compression to the outside air in the cooling water. The cold recuperator heat exchanger and LN2 heat exchanger were adopted aluminum plate-fin proven helium liquefaction refrigerator. Turbo expander, cold recuperator and LN2 heat exchanger were installed in the cold box, other devices were installed as a compressor unit on a single frame. Considering the ceiling height of the cooling system building of Asahi substation, it was making a structure for drawing the body of the vacuum chamber while leaving the top plate of the cold box in the cooling system building.



Figure 5 Brayton refrigerator flow



Figure 6 Brayton refrigerator photo

The results of performance test, the refrigerating capacity of the refrigerator was 5.8kW@77K, and COP was 0.1@77 K, then it was a certain degree of success. Therefore, as a basement of the structure of the circulation system, which was introduced in Chapter 3, we have developed a cooling system equipped with this refrigerator. At the factory testing, the performance of the cooling system, the controllability, and the operability and so on, have been transferred to the Asahi substation after confirming that there is no problem. Currently, in preparation for the long-term continuous operation in a power system on which we plan to start from summer 2015, the final confirmation of the cooling system has been performing.

### 5. Summary

Adaptation of high-temperature superconducting cable to the ILC, we think useful as energy-saving technology to reduce the loss at the time of ILC power supply. In this paper, we introduce the state of the art of refrigeration and cooling systems that have been developed by NEDO "high-temperature superconducting cable demonstration project" of high-temperature superconducting cable that is attracting attention as the future of energy-saving technology.

Demonstration that lasted more than one year, was successfully ended without any big trouble, and it made a big success. However, assuming a future superconducting cable commercialization, it also became clear that there are problems in the capacity of the refrigerator, the efficiency, and the reliability. Therefore, development of large capacity, high efficiency, high reliability of the refrigerator was carried out.

The refrigerator using turbo compressor and the expander, aimed large capacity, high

efficiency, and high reliability, by reverse Brayton cycle, multi-stage of the compressor, and the adoption of magnetic bearings. The results of performance test, refrigeration capacity and COP were both able to accommodate certain results. We performed relocation to the Asahi substation. We are currently preparing for the demonstration test connected to the power system in summer 2015.

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# Energy saving and Cost Reduction in High-Voltage Substation and Distribution System for Green-ILC (Tadashi Fujinawa, Riken)

### 1. Introduction

Accelerators are mainly operated nonstop for a long time and require a large amount of electricity. From this point of view, an AC power supply system must be highly reliable, economical, and efficient.

The author proposes a new high-voltage (HV) substation and distribution system using Green ILC, which can achieve energy savings and cost reduction based on the RI beam factory (RIBF) experience of the RIKEN Nishina Center. Using this proposed substation and distribution system, the construction cost will be less than half of that of the technical design review (TDR), and the amount of energy savings will be 9,218MWh per year.

### 2. HV substation and distribution system of TDR

The plan for the transmission and distribution of ILC using TDR was accepted by both Kyusyu Electric Power Corporation and Tohoku Electric Power Corporation and is excepted to supply 275kV, according to the report of the Large-Project Division of AAA two years ago (2013).

Fig. 1 shows the general plan. Fig. 2 shows the main substation single-line diagram (SLD). Fig. 3 shows the SLD of a 66kV/6.6kV [HV/medium voltage: (HV/MV)] substation.

This plan was designed by an engineering consultant company requested by the High Energy Accelerator Research Organization (KEK), which is simply an expansion of KEK and the J-Pack facility.

Fig. 4 shows a photograph of the RIKEN Nishina Center HV/MV substation for reference.

The author expresses some doubts on the plan and will present my comments and explanation of each item.

1) Receiving voltage

TDR plans 275kV as the receiving voltage, but Kyusyu Electric Power

Corporation does not have a 275-kV system. It uses 220kV instead of 275kV. The power receiving voltage in the Kyusyu area is 220kV, and no other voltage option is available.

In the Tohoku area, the supply voltage is 154kV for a 200-MW load. In addition, the JFE Steel Corporation Chiba Works and Nippon Steel & Sumitomo Metal, both in Chiba Prefecture, and the Kashima Kita (north) Industrial area where Mitsubishi Chemical Corporation has its flagship



Fig.1 This drawing shows that the 164-MW power will be received at 275kV/66kV main substation from the utility company, and power is distributed to the seven 66kV/6.6kV HV/MV substations using 66kV underground cables. The received power at each HV/MV substation is less than 30MVA.

project receives 154kV from Tokyo Electric Power Corporation. The Kashima Minami (south) industrial area uses 66-kV distribution systems. Kashima area is in the Ibaraki Prefecture. The only example where a 275-kV supply exists is in Tohoku-epco for the East Japan Railway.

2) Economic performance

The 275 kV-transmission lines are directly connected to large power stations and create a basic power grid. However, in Japan, the manufacturers of 275-kV equipment are only Hitachi, Toshiba, and Mitsubishi Electric, and the equipment is very expensive compared with that in the 154-kV system. In addition, an expensive microwave tower and its communication systems are required in the 275-kV substation in the Tohoku-epco area. We have to note that a 275-kV substation requires a first-class licensed engineer (which is currently rare after the Fukushima Daiichi Nuclear Power Station disaster), whereas a second-class engineer is required for a 154-kV substation.

The Large-Project Division of AAA has estimated an HV substation system. Under the same voltage, a 60-Hz transformer will cost lesser than a 50-Hz transformer because the 60-Hz transformer is smaller than a 50-Hz one. However, in a 220-kV versus 154-kV system, the 50-Hz transformer has an advantage in terms of cost.

The TDR plan has twice the capacity and spare power; thus, we must consider the economic aspect. With this design, not only the construction costs but also the operation costs increase. The large number of transformers causes more iron loss (no-load loss), and the series connection of the 275-kV (154kV/66kV and 66kV/6.6kV) system creates large losses from both hysteresis and Joule heating losses.



Fig. 2 The 275-kV/66-kV main substation is heavily-protected. NC means normal close (ON), NO is normally open (OFF). This SLD shows four times the number of 100-MVA transformers compared with a load of 164 MW as shown in Fig. 1. This plan also shows two extra gas circuit breakers (GCB). The areas colored pink and blue are layout of the 66-kV vacuum circuit breakers (VCBs). The feeders from A and B are connected to the 66-kV/6.6-kV HV/MV substations with the 66-kV underground XLPE/PVC cables.



Fig. 3 SLD of the 66-kV/6.6-kV substation. The seven HV/MV substations are arranged. Each substation has loads from 10 to 15 MW, but the transformer capacity is 60 MVA. This drawing shows an emergency 6.6-kV generator and capacitors for conventional power factor improvement, but the capacities are unknown.

3) Reliability

The TDR has two lines for power reception: one is for normal use, and the one is for spare. However, the two lines are installed in one tower. From our experience, a jet plane simultaneously severed two lines due to engine trouble, and a crane ship severed two lines above a river. Both created long-time power outages. The two lines are connected to the same power source (substation). Thus, in the event of substation trouble, both lines will be de-energized.

A two- line power receiving system can be considered useful only for scheduled power outages, although it is costly. The RIKEN Wako campus employs the same system yet still experiences sudden power outages.

The most serious concern is the series connection of the HV/HV and HV/MV transformers. If one of them is damaged, the system will not work. Therefore, the two sets of equipment have a two times probability of failure compared with one set.



Fig. 4 RIBF substation. The front is a 66-kV gas-insulated substation with a VCB. The back row shows a transformer with a capacity of 25/30 MVA and the 6.6-kV metal-clad switch gears behind.

3. Proposed plan for Green ILC

Fig. 5 shows the proposed plan of the HV substation and distribution system made by the author.





Fig. 5 SLD of the energy-saving system. The drawing corresponds to those shown in Figs. 3 and 4. Green ILC will arrange two switchyards and receive power from different power utility sources such as the A and B substations. The two lines are energized at all times and supply power via four 60-MVA HV/MV transformers. In case one line is de-energized, the green normally off GCB will switch on immediately and supply power within 6 Hz (12 ms). With this almost uninterruptible power supply system, we can operate cryogenic refrigerators, vacuum systems, and other important loads without interruption.

First, the voltage should be 154kV from the Tohoku-epco area, which was recommended by the Large-Project Division of AAA. The 275-kV system cost is very high compared with the 154-kV. In addition, the Tohoku-epco has no plan of supplying 275kV at all.

Green ILC has two switchyards and receives power from different power sources of Tohoku-epco. In case the total required power is 200MW, both substations will supply 100MW each. One normally off GCB is installed in between. If one side experiences a sudden power failure, the high-speed under-voltage relay automatically orders the GCB to "switch on," as indicated by the green color. From this action, we can operate cryogenic and other systems without interruption. The main distribution cable size is two 325mm<sup>2</sup>, and the feeder cables are 150mm<sup>2</sup>. The main cable capacity is 240MVA, and the allowable power in each feeder is more than 60MVA. This type of different power supply system can be used in government prefecture and other essential loads.

The required transformer sets will only be four 154kV/6.6kV (HV/MV) 60MVA, and they will be distributed at the same interval. From this setup, this system does not require 154-kV/66-kV HV/HV transformers, and savings in terms of losses from the said HV/HV transformers can be realized. The 14 transformers in the TDR will be converted to only four transformers, thus a significant savings in terms of lesser number of circuit breakers, disconnect switches, bus bars, and other equipment will be realized. In addition, fewer parts mean fewer troubles, which increase reliability.

The reason for the HV/MV is that it has two windings of 6.6kV 30MVA for the MV circuit breaker maximum capacity of 3,000A, which makes the MV side achieve a maximum capacity of 30 MVA. I believe that TDR chooses 66kV/6.6kV for the 30MVA transformers.

The construction cost of the proposed system is approximately half that of the TDR system owing to its fewer equipment and simple structure.

The performance of both systems can be quantitatively calculated. The conditions are as follows:

The power requirement of Green ILC is 200MW. The amount of  $CO_2$  emission from Tohoku-epco is 0.591kg/kWh in 2014. The electrical cost is  $\pm 12$ /kWh. The operation time of Green ILC will be 7,000h/year. Fig. 6 shows the transformer efficiency: one 100 MVA, seven 30MVA, and eight 60MVA.

TDR system:  $(4 \times 100 \text{MVA} + 14 \times 30 \text{MVA})$ 

- 100MVA at 50% load, η= 99.49 at 50MW: 1 0.9949 = 0.0051; 50MW × 0.0051 = 255kW. 4 × 255 = 1.02MW (total). The iron loss is 125kW for a total of 4 × 125kW = 500kW.
- 2) 30MVA at 47.6% load, η= 99.545% at 14.3MW: 1 0.9945 = 0.0055; 14.3 MW × 0.0055 = 79kW. 14 × 79 = 1.1 1MW. The iron loss is 22kW for a total of 14 × 22kW = 308kW.
- 3) Total loss

During operation: 1.02MW + 1.11MW = 2.23MW During maintenance: 500kW + 308kW = 808kW (1,760h/ year) Green ILC system:  $(154kV/6.6kV, 60MVA \times 4)$ 

Load factor is 83% of the 60MVA, which is 50MW.  $\eta$ = 99.40%: 1 - 0.994 = 0.006;

 $4 \times 0.006 \times 50$  MW = 1.2MW (almost half). The total iron loss is  $4 \times 50$  kW = 200 kW.

The comparison of both systems is presented as follows:

Energy loss during operation time: 2.23MW - 1.2MW = 1.03MW (7,210MW/year) During maintenance: 808kW - 200kW = 608kW (1,070MWh/year at 1,760h/

year)

Total: 7,210MWh/year + 1,070MWh/year = 8,280MWh/year

Electrical cost of transformer loss:

During operation: 1,030KW × 7,000h/year × 12/kW·h = 86,520,000.00/year During maintenance: 608kW × (8,760 - 7,000) × 12/kW·h = 12,840,960.00/year Total amount: 86,520,000.00/year + 12,840,960.00/year = 99,360,960.00/year

CO<sub>2</sub> emission

During operation: 1,030kW × 7,000h/year × 0.591kg/kW·h = 4,261,110kg/year During maintenance: 608kW × (8,760 - 7,000)h/year × 0.591kg/kW·h = 632,417 kg/year Total: 4,261,110kg/year + 632,417kg/year = 4,893,527kg/year = 4,894ton/year.

### Cable loss

The cable size capacity is same as the capacity of the transformers. The calculations were made by PAT No. 263544. The other conditions are same as those in the transformer loss calculations.

TDR system

1. 66kV XLPE/PVC Cable 150mm<sup>2</sup> for 14 feeders

- 2. Each cable length is as follows :  $4 \times 11.65$ km,  $4 \times 7.7$ km,  $4 \times 4.1$ km, and  $2 \times 0.4$ km
- 3. The current is 125A (14.3-MW base); the conductor temperature is 49.1°C.
- The cable losses are 25.2kW for 11.65km, 16.6kW for 7.7km, 9.0kW for 4.1km, and 0.9kW for 0.4km.
- 5. The total loss is 205kW or 1,435,000kW·h/year; the CO<sub>2</sub> emission is 848tons per year.

Green ILC system

- Main cable: 154kV XLPE/PVC 2 × 325mm<sup>2</sup> (51.4°C at normal current of 450A and maximum current of 900A)
- Transformer feeder cable : 154kV XLPE/PVC 150mm<sup>2</sup>, 225A at 60MVA and 200A at 50MVA at 69.5°C.
- 3. Each cable length is as follows: for the main cable— $2 \times 6.2$ km and  $2 \times 3.1$ km; for the feeder cable—0.4km.
- Cable losses: main cable —for 2 × 6.2km, 375A at 100MW is 56kW and for 2 × 3.1km, 188A at 50MW is 6.9kW. The total loss for the four cables in the feeder is 8.1kW.
- 5. The total cable loss is 71kW. The electrical loss is 497,000kW/year. The CO<sub>2</sub> emission is 294tons.

Difference between the TDR and Green ILC:

- Cable portion: 1,435,000kW·h/year 497,000kW/year = 938,000kW/year. (¥11,256,000.00)
- Grand total: 9,218MWh/year, ¥110,616,960.00/year, and 5,448tons of CO<sub>2</sub> per year. We can consider this as monergy.

#### 2015年2月5日 三菱電機株式会社 系統変電システム製作所

#### <u>100MVA油入変圧器の効率曲線</u> Efficiency Curve

1. 変圧器仕様

特別三相, 50Hz, 導油自冷式, 負荷時タップ切換器付, %Z=11%, 内鉄形, 騒音値65dB(防音壁付) 一次側: F168~R154~F140kV, 星形 二次側: 66kV, 星形 安定巻線(三角形)付

#### 2. 損失

無負荷損失(鉄損) 125 kW Iron Loss 負荷損失(銅損) 530 kW Copper Loss 補機損失は含みません。 ※損失は参考値であり、変圧器の仕様変更、詳細設計により変わる可能性があります。

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3. 変圧器の効率曲線
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SDT-K·8734 (1/3)

Fig. 6 TDR main transformer efficiency curve. 154kV/66kV, 100MVA, 99.35% at rated capacity.

#### Efficiency Curve 30MVA油入変圧器の効率曲線

2015年2月5日 三菱電機株式会社 系統変電システム製作所

#### 1. 変圧器仕様

三相, 50Hz, 油入自冷式, 負荷時タップ切換器付, %Z=15%, 内鉄形, 騒音値65dB 一次側: F72~R64.5~F57kV, 星形 二次側: 6.9kV, 星形 安定巻線(三角形)付

#### 2. 損失

無負荷損失(鉄損) 22 kW Iron loss 負荷損失(銅損) 190 kW Copper loss ※損失は参考値であり、変圧器の仕様変更、詳細設計により変わる可能性があります。

#### 3. 変圧器の効率曲線



#### SDT-K·8734 (3/3)

Fig. 7 TDR HV/MV transformer efficiency curve. 66kV/6.6kV, 30MVA, 99.30% at rated capacity.

#### Efficency Curve 60MVA油入変圧器の効率曲線

2015年2月5日 三菱電機株式会社 系統変電システム製作所

#### 1. 変圧器仕様

三相, 50Hz, 導油自冷式, 負荷時タップ切換器付, %Z=15%, 騒音値65dB, 内鉄形 一次側: F168~R154~F140kV, 星形 二次側: 6.9kV, 星形 安定巻線(三角形)付

#### 2. 損失

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無負荷損失(鉄損)
50 kW Iron Loss
負荷損失(銅損)
370 kW Copper loss
補機損失は含みません。
※損失は参考値であり、変圧器の仕様変更、詳細設計により変わる可能性があります。
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3. 変圧器の効率曲線
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SDT-K·8734 (2/3)

Fig. 8 Green ILC transformer efficiency curve. 154kV/6.6kV, 60MVA, 99.30% at rated capacity.

### 4. Conclusions

The system that the author has proposed is the so-called "Green ILC system," which offers a large reduction in the construction cost of more than twenty billion yen, and the operating cost will be more than one hundred million yen per year lower than the TDR system. In addition, the Green ILC system reduces the  $CO_2$  emission by more than 5,000tons per year, a fact known by everyone.

We plan to use a superconducting cable for transmission and distribution. However, the cable loss in the Green ILC system is only 71kW. The author has some doubts whether a superconducting system, which requires cryogenic refrigerators can be sustained. This aspect must be very carefully studied.

Some people might worry about the direct transformation from 154 to 6.6kV. In fact, in Japan, many residential transformers from the nuclear power stations use 500kV/6.6kV. In addition, the Korea Proton Engineering Frontier Project has also a 154-kV/3.3-kV system.

The ILC system will provide large advantage derived from nuclear physics, but its need for huge consumption of electricity would be its weak point. Not only the construction cost but also the operation cost should be considered for the Green ILC, which the author has explained in details earlier.

# Introduction of Friction Reduction Chemicals for water pipes (Hiroyuki Nishi, Sin-Nihon Kucho)

### 1. Introduction

The method adding very small amount of pipe friction resistance reducing agent in the circulating water piping (Drag Reducing Additive: hereinafter referred to as DR agent), has been known technique to reduce the carrying power of the pump. This DR agent is used polymeric agent or a surfactant. Practical use of a surfactant has a long history, and has many examples, such as an increase in the navigation speed of the ship, improvement of the water discharge capacity for fire fighting, and oil pipeline transport capacity, they are examples of to transient flow field.

However, in the circulatory system DR agent will be destroyed its molecular structures by the mechanical shearing force such as a pump impeller, there is a problem of deterioration of the DR agent. Surfactant, on the other hand, because there is a regenerative capacity which will be mentioned later, become the mainstream in recent years of research carried out basic research and field tests in abroad. In the regions of the district heating pipes in Europe, it is used in practice. In Japan, it reached the stage of practical use from the basic research stage, the examples of the use have been increasing.

Shin-Nihon Kucho has about 15-year career and achievements with respect to DR agent introduction as energy-saving technology of air conditioning piping system. We introduce the basic characteristics of the DR agent description and example of application to the air-conditioning piping to the existing commercial building in this paper. It is our hope to help deep understanding DR agent for Green ILC WG participants, in turn, project promotion.

### 2. Mechanism of DR effect

When water is flowing in the pipe at a certain speed, water molecules at the pipe inner wall and the central portion disarray intensely in the flow, that is, the "turbulent flow" state. Most of the piping friction resistance rises due to the turbulent motion. Thus, by suppression of turbulence (laminating of the stream), the pipe frictional resistance can be reduced significantly. In Moody diagram showing the relation between the Reynolds number and the pipe friction coefficient in Figure 1, the friction coefficient of the turbulent flow is to close an extension of the diagram of the laminar flow zone shown by a broken line. This is a DR material has been developed for the purpose (the effect is called DR effect).



Figure 1 Moody chart

DR effect which was discovered by B.A. Toms in 1948 is a phenomenon which is also referred to as Toms effect. As the material of the DR agents, surfactants and polymeric agent is used. For example, by adding small amount surfactant to flowing water, collection of the surfactant molecules that form as if long chains as shown in Figure 2 (rod-like micelles) can modify the water flow to the non-Newtonian fluid, even rod-like micelles can be destroyed by mechanical external force, it will recover. While fresh water is Newtonian fluid is the constant viscosity regardless of the shear rate, the non-Newtonian fluid viscosity varies with shear rate. As shown in Figure 3, pipe flow state is almost the same as a fresh water at near-wall where is a large shear rate with small viscosity, at the center, since the place is in a large viscosity with small shear speed, the flow become small disturbance massive flow, then, turbulence is suppressed and the pipe frictional resistance is reduced.


Figure 2 the molecular structure of the surfactant, and rod-like micelles in the flowing water



Figure 3 changes in the pipe flow state

### 3. Characteristics of DR effect

DR agent that we are using, is cationic surfactant of Ethoquad system, added counter ion conducive to form rod-like micelles, it is a product that also has anti-corrosion effect. DR effect determine mainly "flow velocity in the pipe", "the temperature of the circulating water", and "concentration of DR agent". As "flow velocity in the pipe  $(1m / sec \sim 4m/sec)$ " is faster, and as "the temperature of the circulating water  $(5^{\circ}C \sim 65^{\circ}C)$ " is higher, and "concentration of DR agent (stock concentration 500ppm ~ 1,000ppm)" is higher, DR effect tends to increase.

Figure. 4 is a data of DR effect in the straight tube portion with stock concentration of DR agent 1,179ppm and 500ppm, has to organize the DR effect by the pipe flow velocity and temperature as a parameter. The DR effect is approximately up to 80% where DR effects increase by an increase in flow speed and temperature. Although, at the low concentration 500ppm, DR effect is greater at low flow rates range, if it exceeds a certain limit in the high flow rate region, the rod-like micelles is destroyed in a turbulence intensity and then DR effect is lost. Also in the joint portion of the curved

portion, because of large turbulence intensity originally, DR effect can not be expected.

In addition, both of straight tube portion and the joint portion, for viscosity increase due to DR agent additive, sometimes DR effect is negative at below 1m/sec of the low flow rate region, where the viscous resistance becomes dominant.



Figure 4 DR effect of straight pipe section

The DR effect is up to 80% in the straight pipe section, on the other hand, for the effects of the resistance in the joint portion of and the resistance of the equipment inside are dominant in DR effect of the entire piping system, overall DR effect is shown in Figure 5. DR effect of the entire piping system will be determined by the ratio of the DR effect of the straight pipe portion resistance to total resistance (corresponds to a pump total lift).



Figure 6 shows the effect of DR additive to fin and tube type air/water heat exchangers

which are used in air-conditioning fan coil unit. DR effect, because it is brought by the turbulence suppression, cause a reduction in heat exchange efficiency if generated in the heat exchanger tube. The heat exchange efficiency is hardly reduced because DR effect is relatively small in the case of cold water, reduction in heat exchange efficiency due to the relatively large DR effect is assumed to have occurred in the case of hot water. In DR agent case study on our company's existing commercial building, reduction of heat exchange efficiency is not observed for cold water heat exchanger.

However, decrease in heat exchange efficiency due to the DR effect in the internal heat exchanger can not be simply assessed, because of dependence on the diameter of the tube, the length of the straight pipe section, also the influence of the shape of the inner wall. For applying the DR agent to specialized equipment which is different from the commercial air-conditioning, it is expected to require more detailed examination and verification.



Figure 6 impact on the heat exchange efficiency of the fan coil unit

#### 4. Input conditions of DR agent

Are shown below nine conditions  $((1) \sim (9))$  is a study item at the time of the DR agent input for the existing business building. Since  $(1) \sim (3)$  is a necessary condition, it can not be applied on as long as it does not meet this. (4) ~ (9) is not a necessary condition, since the higher the initial cost and running cost, since the cost-effective worse, the possibility that results as the input becomes unsuitable.

As for ①, the circulation of the water is significantly inhibited by capturing the gas bubbles into the circulation water, if it is an open circuit rather than a closed circuit. It should not be applied on because there are cases in which bubbles are blown out from the expansion tank. For O, when components such as iron and zinc of the circulating water is at high concentrations, the expression of DR effect is interfered. In addition, since surfactant component is adsorbed on the rust that is generated inside the pipe, and is to peel off the rust which may inhibit the flow of the circulating water, DR agent can not be introduced into the system piping where internal corrosion has progressed. For O, because the circulation amount of water due to the reduction of piping resistance increases only by applying DR agent, the carrying energy of the pump is increased. Therefore, it is essential to control or to adjust so as to be a proper flow rate by the inverter or something.

• DR agent conditions for input (for the existing business building)

1) it is a closed circuit.

② water quality and piping internal corrosion is within the allowable range.

③ it is a inverter control pump (or manual inverter adjustment).

④ the flow rate is relatively fast in the system (more than 1.5m/sec).

⑤ resistance ratio at straight pipe section is a relatively large in the system.

(6) chilled water system or similer piping system (hot water system is unsuitable).

⑦ no using rust inhibitor incompatible with the DR agent.

(a) measurement environment (pressure, flow rate, the amount of power) are in place.

(9) the pump has a mechanical seal.

## 5. Case example of DR agent introduction

We introduce the reality of DR effects and energy-saving effects based on the real case, although it is not possible to state the magnitude of DR effects unconditionally, where the air conditioning piping system has a variety of characteristics, such as the ratio of the resistance for straight pipe section and the rest (resistance of internal joints and equipment) depending on the design of the building equipment, difference of pipe flow velocity, flow rate change throughout the year, and properties such as temperature.

Building as a target of case studies, which is the 20th floor above ground, in the total floor area of about  $50,000m^2$  merchandise store building, is a DR agent application example to a heat source water piping system (for water heat source package air conditioning), where heat source water pump is a 15kW x 3units (parallel operation and constant control of discharge pressure).

In Figure 7, it is shown piping resistance curves, two of the upward curves showing the measured result of the circulation flow and the pipe pressure loss of the input before and after the DR agent of the building. At the rated flow rate at three pump operation (circulation flow rate 100%), the piping pressure loss after turning-on (DR solution) has been reduced by 13% compared to before (pure water). Reduction of the pipe pressure loss, that is, the DR effect.



Figure 7 actual measurement result of the circulation water and the pipe pressure loss

Figure 8 is a plot obtained by actually measured the power consumption and the circulation flow rate, based on the measurement of the pressure and the flow rate of input before and after shown in Figure 7, in a state after the appropriate control settings change. Although, for the circulation flow rate less than 80m<sup>3</sup>/h, it was about 13% of the energy-saving effect with one pump operation before and after, it was about 37% of the energy saving effect together with operating unit reduction effect, for the circulation flow rate around 100m<sup>3</sup>/h and since after applying DR solution operating pump units became one. The energy-saving effect through the year is determined by whether how much of the load flow rate change occurs in how much of the frequency, since circulation flow rate is constantly changing in the actual operation.



Figure 8 actual measurement result of the circulation water and the pump power consumption

In Figure 9, the occurrence of each load flow rate (in every 10%) when the maximum flow rate designed to be 100% are shown in the bar graph by a respective measurement of one year before and after the introduction, in the case of the same building that was introduced case above. Total operating time of year was a 5,475h, one pump operation time after application was increased to 3,534h, where an operating time of the before was a 2,776h, and 3 pumps operating time of the before was 557h was reduced to 37h against. In other words, it can be seen a number of operating unit reduction coming from the effect that the average number of operating units of the pump was decreased.



Figure 9 pump operating time with each load flow rate of year time occurrence

When we estimate the power consumption of the year for each load flow from Figure 8 and Figure 9, it is Figure 10. From this result, the annual power consumption 72.8MWh/year before application, it becomes 52.2MWh/year after the application, and energy-saving effect of the year was about 28%. In particular, it is read a large energy-saving effect in the load flow rate ratio of 40% to 50%.



Figure 10 annual power consumption of each load flow rate

## 6. Summary

This paper is assumed the DR agent application to the air conditioning piping for the existing business building, the findings are summarized below.

(1) it is necessary to examine well the appropriateness of the target system before input.

(See "Conditions for DR agent application  $(1) \sim (9)$ ")

(2) Energy saving effect can be easily obtained as the straight pipe section resistance ratio is large. (See Figure 5)

(3) energy savings can be obtained for the first time by carrying out appropriate pressure-flow rate adjustment.

(4) The proper pressure and flow rate adjustment is required overall engineering design based on actual measurement.

(5) hot water system has a possibility that the heat exchange performance degradation occurs. (See Figure 6)

(6) After application, the DR agent concentration management is important.

Nevertheless the auther's understanding of the ILC is not sufficient, the challenges of adopting the DR agent in this project are listed three below;

(1) Acquisition of basic characteristics data in the case of DR agent charged into a large diameter pipe.

(2) Design of the resistance ratio of the straight pipe part and the optimum pipe size in consideration of the energy-saving effect.

(3) Verification and its counter-measure to radio-activation of DR agent.

Reference

[1] Iguchi, Kudo: Evaluation of piping resistance-reducing agent (the 1-3 Report), air conditioning and sanitary engineering Association, academic lecture Papers (2000-2003)

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## High efficiency operation of Data Center (Osamu Takehisa, NTT facilities)

#### 1. Introduction

Data center that houses the computer and data communication equipment has become an important infrastructure that is essential not only for the company but for the entire society. However, power consumption of the data center is increasing year by year. Figure 1 shows the amount of heat generated per rack of ICT equipment by the investigation of ASHRAE. According to the 2012 the latest survey results, the amount of heat generated by the ICT equipment is further increased, it has become a 40 ~ 50kVA per rack with a maximum, and there is a prediction that extends to about 10-fold in 2000 to 2020. Power consumption of the data center will consume the power of 5-10 times more compared to the same scale of the office building.



Figure 1 calorific value trend of ICT equipment

More recent price hike of electricity prices is multiplied by the final blow, power cost reduction has become the greatest challenge of data center business operations. (Figure 2)



Figure 2 Changes in model electricity prices in TEPCO

The power consumption breakdown example of a data center by the Uptime Institute and the McKinsey survey is shown in Figure 3 (The Uptime Institute, The Invisible Crisis in the Data Center 2007). ICT equipment is 56%, the air-conditioning power is 33%, the power supply loss, lighting and others become 11%. To reduce power consumption in this situation, the following three points are important. First, to improve the air conditioning efficiency. Second, to improve the power conversion efficiency. The third is to do optimization throughout total system including ICT equipment, air conditioning, and the power supply system.



Figure 3 power consumption breakdown example of a data center

In Figure 4, it shows the breakdown of the data center facilities investment. This is

the average for conducted hearings on the data center operators by ourselves. It finds that about 75 percent of the capital investment is being used to maintain the existing data center (surveyed 38 companies in December 2012 implementation). The old data centers faced many challenges, because they are unable to stop the service to the equipment specification renewal, and can not be extended by the power capacity shortage despite a space in the server room, etc.



Figure 4 the capital investment breakdown of the data center

NTT Facilities will maximize the value of the data center from the multilateral point of view, by a combination of technology that has supported the communication of Japan and building and energy technology, and by solving the issues for reduction of power costs and personnel expenses, equipment and buildings of aging measures, the issues such as response to the scalability. In addition, we support cost reduction for electricity charges and equipment of the data center, and provide a variety of solutions from the power-saving products such as LED lighting, system development to realize the energy saving, and to consulting, since the data center is to continue to operate a long time, especially energy-saving and cost reduction becomes important. NTT Facilities has carried out about 30% of the design and construction of the entire domestic data center, in 2000 or later, there are building experience about 40 buildings of large-scale data center of more than 5,000 square meters. Also, in addition to the 24 hours operation a day and 365 days a year by the advanced systems that make full use of ICT, we have maintenance staff of experienced professional, which is located across the country about 260 locations of maintenance bases, to deal with rapidly and eligibility at the time of

trouble. Overseas, we have the local subsidiary in the United States West Coast and in Beijing, the branch in Singapore, the partner construction company of the data center in Thailand. There are consulting experience at about 120 sites in the world 30 countries, the design, construction and O&M records in Singapore.

This time, focusing on the energy and cost savings from a variety of solutions, we introduce the solutions for improving the power efficiency and improvement of the air-conditioning efficiency. For the solution for air conditioning efficiency, airflow control system for ICT equipment "aisle capping", smart air-conditioning control system for the data center "Unified Cooling", introduction of efficiency improvement of air-conditioning system by outside air use "indirect outdoor air cooling type of FMACS hybrid", are introduced. For the solutions of power efficiency improvement, high-voltage DC-current system for ICT equipment "HVDC (high voltage DC power supply)" is introduced.

## 2. Solutions for improvement of the air-conditioning efficiency

There is different cause that is not able to efficient air conditioning in the actual data center. As a typical example, the following three are mentioned. The first one, that cold air to cool air for cooling is inhibited, and does not reach to the server. The recent years of data center take the method which is often supplying the cold air from the double floor in the double floor system, however, in the double floor, it has been laying the cable to the ICT equipment, and is often stacked high. Also, the cables being made replacement of ICT devices often can not be removed and buried in another cables. As a result, when the replacement of ICT equipment is followed by cable is piled high, it has often occurred that cold air to the ICT equipment is unable to supply. (Figure 5)





Figure 5 inhibition of airflow (cold)

The second one, adverse heat effects to ICT equipment will occur, by the hot spot and heat accumulation where required cold air can not be placed and the exhaust heat of ICT devices are wrapped around (when it severe, server is down). (Figure 6)



Figure 6 inhibition of airflow (cold)

The third one, the server often become hot at the top, being made of good cooling in the bottom, since it has about 2m height. (Figure 7)



Figure 7 the upper and lower temperature difference at the suction surface

To eliminate hot spots, as a countermeasure 1, is a method of increasing the air volume of the air conditioner cooling, however, energy saving as a whole can not be achieved for sending cooling air flow more than necessary in other locations. As a countermeasure 2, there is a method of lowering the set temperature of the air conditioner, however, energy saving can not be achieved to lower the temperature in the same or also required elsewhere. (Figure 8)

Therefore, here we will introduce the solutions that lead to cost reduction and energy saving.



Figure 8 countermeasures for hot spot

2-1. Airflow control system for ICT apparatus "aisle capping"

The aisle capping, is an airflow control technology to realize the efficient air conditioned environment and is a solution that can be both energy-saving and high reliability in the data center, by partioning a rack passage by walls and roof, and by separating physically the exhaust the (high-temperature) of the IT equipment from the air supply (low-temperature) to the IT equipment. As energy saving effect as a feature, by improving the supply air volume reduction and operational efficiency from the air conditioner, the air conditioning power can be reduced up to 20 percent. In addition, by eliminating the hot spot of the cold aisle, a good air conditioning environment can be achieved. And it has a high seismic performance, mitigation of the supply temperature rise in the event of a power failure. The top panel is removable and can be easily maintained. (Figure 9) (Figure 10)



Figure 9 inhibition of airflow (cold)



Figure 10 Inhibition of airflow (cold)

Also, by calculating the pressure distribution under the floor tailored to the air conditioner and underfloor availability, and by calculating the blow-off distribution commensurate with the airflow in need or with heating value of the equipment, the equipment necessary aperture ratio of the double floor panel and its deployment plan are obtained for properly cooling, and it will be able to suppress the air volume of the air conditioner. (Figure 11)



Figure 11 porous double floor panels with different aperture ratio (aperture ratio: 0% to 50%)

Then, by mounting the blank panel that blocks the hot air flowing through the gap in the rack to the cold aisle to the place of not mounted server equipment in the rack, it is possible to enhance the control efficiency of the aisle capping. (Figure 12)



Figure 12 inhibition of the air flow (cold air)

2-2. Data center for smart air-conditioning control system "Unified Cooling"

Since in large data centers scale power consumption increases, and for the air-cooled package air conditioning system there is a possibility that can not be installed outdoor unit to the outdoor space, there is a growing tendency for cold water use air conditioning system is adopted. In chilled water use air conditioning system, there is divided three functions, the chiller cooled the water (heat source system), a pump for circulating the water (water-based), and air conditioner which performs cooling installed in a server room. These chiller, pump, and air conditioner, it is often that

consists of different manufacturers, it can not be cooperation operation between devices. Therefore, cold water temperature and water supply pressure (water amount) of cold water made by the chiller is operated at a constant set value assuming the maximum cooling load, if the load is not a maximum value, such as a low operation rate of the ICT device, it tend to consume power more than required and to decrease the efficiency. Power consumption of the chiller pump accounted for 60% of the power consumption of the chiller pump accounted for 60% of the power consumption of the entire water-cooled air conditioning system, energy conservation has become a major issue. Therefore, Unified Cooling® is ever performs chiller and pump integrated control that was operated at a constant set value, to reduce power by adjusting the flexible settings. The dedicated developed controller, regardless of the building new construction or old, unifies the information of chillers, pumps, and integrating information of the air conditioner into BACnet which is a standard communication protocol specifications of the BAS, and controls the settings of the chiller pump by monitoring the operating temperature and humidity and air conditioners in the data center. (Figure 13)



Figure 13 Overview of the Unified Cooling®

In addition, Smart DASH collect the suction temperature data of ICT equipment, by the wireless temperature sensor installed in the server rack and the server room, individually automatically controls each of the air conditioners on the basis of the analysis result of collected data. Until now adjustment of the temperature environment has been done manually by a technician-operator, etc., Smart DASH has a learning function, and precision of air-conditioning control is improved through the utilization of a continuous operation, by dynamically respond to the amount of heat change generated by the server, achieve a higher energy efficiency optimum air. It is noted that the air-conditioning control, wireless communication and BACNet, the communication protocol, such as MODBUS are used. (Figure 14) (Figure 15)



Figure 14 System configuration in Smart DASH



Figure 15 Benefits of Smart DASH

By these system, highly reliable and highly efficient integrated air conditioning control can be achieved, and up to 30% power consumption of the chiller and pump can be reduced. In addition, by combining the data center air conditioning automatic control system SmartDASH® of our products, it is possible to make all energy saving for air conditioners, chillers, pump, 2.5 times saving as compared in the case of use SmartDASH® only, it will reduce power consumption up to 30 percent of the entire system of air conditioning. (Figure 16)



Figure 16 effect of reducing power consumption of the air conditioning system

2-3. High efficiency air conditioning system "indirect outdoor air cooling type FMACS hybrid" through the use of outside air

Generally, direct outdoor air cooling method using low temperature ambient air (Figure 17-1) has a case that it is necessary of humidity control to avoid corrosion of the electrical circuit board due to impurities, such as outside air dust and sea salt particles, and in accordance with air introduction amount. With clearing these challenges, we have developed FMACS hybrid (Figure 18) as an indirect outdoor air cooling type air conditioner suitable for data centers where high energy efficiency is required (Figure 17-2). This air conditioner comprises a compressor and a refrigerant pump, a less indirect outdoor air cooling to reduce the influence of external air quality, and high efficiency while ensuring high reliability and availability are realized. The compressor is stopped in winter and in the interim period when the outside air temperature is low, by performing the outside air cooling operation that circulates the coolant in the coolant pump, operation efficiency is greatly improved, since the power consumption of the coolant pump is much smaller than compressor used in a conventional air conditioner. Using the present air conditioner, the annual power consumption and annual  $CO_2$ emissions related to the data center air conditioning are up to 54% reduction (estimated result by the standard meteorological data of Sapporo) as compared to the general computer room air conditioners.



Figure 17-1 direct outdoor air cooling system, Figure 17-2 indirect outdoor air cooling system



As a reference, for condition of the outside air environment of the location, possible year time of direct outdoor air cooling at  $24^{\circ}$ C operation data center estimated from meteorological data of each city, is 5,000hours in Sapporo, 3,500hours in Tokyo. However, because it is necessary to adjust the humidity, it needs to be careful that it is not all for energy-saving time. (Figure 19)



Figure 19 estimated operation time of outdoor air cooling

3. Solutions for improvement of power efficiency

Power supply system, which has been utilized in the central telephone office as a

reliable power supply, are deployed in the data center, in recent years, in consumer electronics, also to distributed power supply, etc. Although previously mentioned, in which the power consumption of the data center is expected to increase more and more in the future, in the NTT Group, as part of the "DC power supply promotion of initiatives policy", as a friendly power supply system to the global environment we are promoting the further research of the DC power supply system. So, we will introduce the solutions related to power efficiency improvement.

## 3-1. ICT equipment high-voltage DC system "HVDC (high voltage DC power supply)."

General ICT devices converts AC power into DC, and operates by further converts the voltage. The ICT equipment in the data center is connected always via a UPS (uninterruptible power supply). Also, since in the UPS the conversion of the AC/DC, and the DC/AC performed, four times in total including conversion in the ICT equipment takes place in the data center. In contrast communication system used in NTT, by feeding the first from the DC 48V in order to reduce the power conversion to twice, a mechanism to reduce the cause of energy loss or damage has been employed for a long time. The company, applying this mechanism, in order to cope with recent ICT devices large power consumption, has provided the HVDC power supply system that enhances the voltage of the supply power to 380V since 2011. (Figure 20)



Figure 20 large-capacity HVDC rectifier system

Compared with conventional UPS systems, by introducing the HVDC power supply system, up to 20% energy saving and 40% space saving is achieved. Cost is also served

at almost the same. (Figure 21)



Figure 21 benefits of the high-voltage DC power supply

Mounting in a rack by the 2013, migration apparatus which can convert the voltage to fit existing ICT equipment (AC100V/200V, DC48V) is also on sale, and is to improve the flexibility of introduction for the spread of HVDC. On the other hand, we have been also promoted movement towards international standards, ICT equipment manufacturers to sell the HVDC-enabled products are gradually increasing. In addition, such as there is also a movement to standardize the connector or plug of the power, it is expected the spread in the future. (Figure 22) (Figure 23)



Figure 22 Overview of HVDC power supply system



Figure 23 migration devices, and HVDC outlet bar and power plug

As an example of an introduction effect of HVDC, in the system of Figure 24, comparing HVDC power supply system efficiency with the AC power supply system, it is improved by 11%, and there is a reduction of 108000kWh per year of power consumption. As a result, about 1.3-million-yen reduction in electricity rates over the years, and there is a reduction of  $CO_2$  emissions by about 36.5t. This is equivalent to the  $CO_2$  absorption amount of forest 10.2ha (2.2 times Tokyo Dome area). (Since this introduction example is one of the cases, at the time of the actual introduction system configuration quantity, etc. are different, then result might be different.)



Figure 24 System Comparison (Example)

ruble i power consumption and comparison of electricity prices			
電源システム	HVDC 給電シス	交流給電システム	差
	テム	(UPS)	
年間消費電力量(万	85.2	96.0	10.8 万 kWh
k Wh/年)			
年間電気料金(百万	10.7	12.0	130 万円
円/年)			
年間 CO <sub>2</sub> 排出量(t	289.7	326.2	36.5 t
/年)			

Table 1 power consumption and comparison of electricity prices

## 4. For the future

In recent years, we often hear DCIM as data center-related keywords (Data Center

Infrastructure Management). Data center operators, by DCIM introduction, has the advantage of energy conservation and cost reduction. The DCIM is integrated management method for ICT equipment, power supply equipment, air-conditioning system, the resources that make up the data center such as rack space etc., and for facility management techniques to support the optimal operation of the data center. In our company regarded the followings as "DCIM", that is, from the design, construction and procurement, to operation, maintenance, and analysis, and the "management cycle" itself, including the planning and consulting. From "Connecting", "Accumulate", "Showing (the show)" various data to the "Use (to find customer value)", and further to realization of the "Prediction", "Action", we have strength to realization of DCIM where no other companies having, then we will further study and as able to offer.

## Smart Community (Takahumi Shimokochi, Takenaka)

1) ILC and smart community

Although there is no clear definition against smart community, in the "Basic Energy Plan" [1] of Japan, it is marked as "a certain scale of the community, while using a distributed energy such as renewable energy and cogeneration, and building through energy management systems that utilize technology such as IT and storage batteries, comprehensively manage the energy demand in distributed energy systems, as well as optimize the utilization of energy, a new social system incorporating also other life support services. " In addition, Figure 1 is shown as an image [2].



Figure 1 image of smart community [2]

In the ILC, about total floor area in the central campus and the experimental site 254,000m<sup>2</sup> of ground facilities have assumed, international science and technology research sphere, such as shown in Figure 2, is envisaged [3]. Campus building with smart community, town planning is an important point of view also in the ILC. We will introduce a demonstration cases and building cases which Takenaka is doing in the following.



Figure 2 Deployment image of ILC international science and technology base to construct a research area and District [3]

## 2) Energy management that utilize cloud

"Building communication system", information and control platform of building equipment that was developed by Takenaka, is a system to capture the changes in the building and out of the environment and information, to create the cooperation of the building and "people" by lobbying to users, and to activate the activity of the "people" and the "town".

"Building communication system", creates added-value such as the automation of control to realize the energy saving and demand response and productivity improvement by analysis and show of various sensor information, and aims the creation of convenient and attractive space for the user.

In addition, not only the building itself, it is possible to centralize the information of city block area, and to contribute to the rationalization of the various management, such as optimization of energy in the area, the formation and activation of the area within the community. Through this system, by cooperating people such as landowners, tenants, visiter, the system operator, a sustainable area management can be build. (Figure 3)



Figure 3 energy management that utilize cloud

 Energy management by regional cooperation example: An Empirical Case Study in Osaka Business Park

(1) work style that utilize a shared space

Building distributed workspace outside or the indoor of the building with less energy consumption, the work styles free to choose space depending on the preference of worker and comfort were realized. Also, by sending environment information and congestion level in real time to match the indoor or outdoor preference of the worker, the use of a variety of space to the worker was encouraged.

Thus, amount of moving to a distributed workspace is reduced the energy of the office room, but also workers for performing the activities even outdoors without staying office, the bustling of the city was created. (Figure 4)



Figure 4 work style that utilizes a shared space

(2) Taking advantage of the EV in the region to demand response and BCP

For the realization of a low-carbon society, with a view to conversion to company's car to an electric vehicles (EV), and plug-in hybrid (PHV), we promote technology demonstration project of power supply system utilizing a battery of EV·PHV.

We have developed a new energy management system that leads to energy load control by EV·PHV and charging/discharging at the same time to EV·PHV, which are Japan's first five EV·PHV. (Figure 5)



Figure 5, taking advantage of the EV in the region to demand response and BCP

## 4) three-dimensional urban Abeno-harukas [4]

"Abenobashi Terminal Building(Abeno-harukas)" is a building height of 300m that contains the stations and department stores, office, hotel, museum, observatory, such as a variety of applications, as shown in Figure 6. It aims to "energy-saving three-dimensional city", and various technologies have been applied.





Figure 6 building outline and appearance

(1) using the natural energy ventilation and lighting system: Eco-void

Void provided in the building each place, it becomes a light and for air passage, are in gently connecting the external and internal. (Figure 7)

## VOID1 hotels Void

«Hotel daytime and night»

In the four seasons, it leads a comfortable outside of the air in the spring and autumn to Eco-void. Air that has passed through the void flows gently to the hotel hallway. Air in the void is deprived corridor heat, and is exhausted from the top.

VOID2 office Void

«Office daytime and night »

Comfortable outside of the air in the first half, gently flowing to the office, such as refresh corner through the void.

«Office night»

To introduce the night of cool air to the office, to cool the offices by night purge, to reduce the air conditioning energy for the next day.

VOID3 department store Void

«Department store daytime and night»

There are a lot of air, which is air conditioning in the department store where people gather many. Through the void without discarded as it is reused to cool the machine room.

«Department store night»

Department store cooling is required even in winter, in a night of cool air, cool the precursor enough by night purge, to reduce air conditioning energy for the next day.

(2) Comfort and energy saving and space by two glass: double skin

By the glass curtain wall for the outer wall of the building, a great view has spread. A double skin structure by the float laminated glass and Low-e double-glazed glass, we have adopted the air flow window system that does not leak the outside of the heat into the room. A high heat insulating shade is installed between the glass and the glass, thereby reducing the air conditioning load. (Figure 8)





Figure 7 Eco-void

Figure 8 double-skin structure

(3) Power generation utilizing the garbage generated in the building: biogas power generation

From garbage such as department stores and hotels, a bio-gas as a fuel is produced. As well as reduce the amount of waste discharged outside of the building to 0, the generated biogas is used, such as in power generation and hot water as a fuel.

It was introduced a state-of-the-art energy-saving technology that make the biogas power generation by using the garbage generated in the hotel and department store restaurant, for the first time in high-rise buildings in Japan. (Figure 9)



Figure 9 biogas power generation

(4) Energy saving in the comfortable office lighting: toning-dimming LED lighting

In Abeno-harukas Building, it is an important theme to be a comfortable for people while achieving energy saving. Depending on the season and time of day, it captures the natural light well, to illuminate gently with LED lighting (toning-dimming). In energy saving, in fact we are aiming to expand the pleasant "new comfortable area". (Figure 10)



オフィスでは調光調色可能な LED 照明を導入します

Figure 10 toning-dimming LED lighting

(5) High-efficiency energy system

By a combination of equipments with small environment load of high efficiency, we are building an energy system that can be friendly to the redundancy and safety relief and excellent maintainability in a space-saving. When there is a room and transportation benefits, we performs heat interchange to aged existing heat source. Others, a high-efficiency heat pumps which collect cooling exhaust heat and biogas generation equipment for heat recovery were installed. To reduce the valuable energy such as electricity and gas, we utilize natural energy, such as ambient air. (Figure 11)

(6) Energy saving promotion system by making the energy visible: A-EMS

In the case of motor vehicles, we check the speedometer, then operate the brake. Similarly, in the case of the building, there is a need for energy meter. The A-EMS, is a system making energy visible, and making everyone involved for performing management of participants. By interact with it, we are aiming to continue a reducing of  $CO_2$  activities and reducing waste of energy. (Figure 12)



Figure 11 highly efficient energy system



Figure 12 A-EMS

(7) Leveling of energy load using the store-hours difference: peak cut

The hotel at night, the office on weekdays at day, department stores on holiday use a lot of energy. The leveling of energy load using business time difference, contributing to energy conservation. (Figure 13)



Figure 13 Leveling of energy load

(8) The energy conservation by heat exchange between applications: area heat recovery Because a lot of people gather in the department store, cooling is required throughout the year. The exhaust heat for the cooling has also used for hot water supply of hotel rooms. The efficiency of energy by the exchange of heat between the area, contributing to energy conservation. (Figure 14)



Figure 14 Area heat recovery

### 5) Summary

For smart communities, various initiatives are mentioned, demonstrated cases have also been reported. Here, we introduced the "Abenobashi Terminal Building (Abeno-harukas)", as a demonstration cases and building cases in Osaka Business Park. In order to be inclusive green ILC of not only laboratory equipment and facilities, but around the facility, even in the ILC of the campus building and town planning, these systems and the technology might be made to the reference.

Reference

[1] http://www.enecho.meti.go.jp/category/others/basic\_plan/pdf/140411.pdf

[2] http://www.meti.go.jp/policy/energy\_environment/smart\_community/doc/smartcommu.pdf

[3] http://lcdev.kek.jp/LCoffice/OfficeAdmin/Test/images/KEK\_Report2013\_5.pdf

[4] http://www.abeno.project-takenaka.com/

# 5 Energy recovery, Energy storage,

# **Energy control of Accelerator**

## Energy Recovery from ILC beam dump (Junpei Fujimoto, KEK)








## Status of charged particle acceleration and deceleration by Plasma (Mituhiro Yoshida, KEK)

<b>プラズマによる荷電粒子の加速・減 速に関する研究の現状</b> <sup>第6回AAA グリーン-ILC WG 会合 2015.02.18 吉田 光宏 (KEK)</sup>	Novel Accelerator (新奇加速)の技術開発 ・超高電界加速器の技術開発: - 高Q ⇔ THz THz:レーザー、電子ビーム、非線形光学素子 - 光伝導スイッチ
加速器の電界を大幅に上げるには ・ <u>耐圧の高い媒質</u> × 金属 @	現時点で成果が出ている新奇加速方式 レーザー駆動加速器 レーザーブラズマ加速(LWFA) ビー <b>ム駆動加速器</b> 誘電体加速(DWA) Drive beam Acceleration beam





#### High density electron beam in KEK LINAC • Injection for the SuperKEKB (5nC, 7GeV) Ultra high field experiment - Beam driven accelerator (DWA, PWFA) - Injector for laser plasma accelerator (After burner) Photon generation

• Low emittance ( < 10 mm mrad ) Advanced • High charge (> 5 nC) RF-Gun • Short bunch length (fs) 4-stage bunch compression  $\rightarrow$  Bunch shape control / precise syncronization



Gradient : PWFA(>30GV/m), DWA(>16GV/m). Total acceleration voltage : > a few 10 GeV.

At FFTB experiment













# Utilization of Stored Energy in Iron (Kenji Hosoyama, KEK)





























# Introduction of high efficiency co-generation system using Gas-Engine (Ryusuke Osaki, MHI)























### 6 Installation of Renewable Energy

### into Accelerator

## Examples of New Energy Power Plants for the Green ILC (Tadashi Fujinawa, Riken)

#### 1.Abstract

Construction of the International Linear Collider (ILC) in Japan will soon begin. This facility will be very large, so it will also consume considerable energy. It will operate continuously for 7,000hours per year. Thus, it is necessary not only to consider how to save energy, but also to introduce new kinds of energy, including renewable energy, for use in the ILC.

The government declared that renewable energy should account for between 23% and 25% of all electrical energy sources in 2030. However, renewable energy sources currently provide only 10% of all energy. A large portion of those sources are hydro-powered, but no suitable locations for additional hydro-power generation remain.

In this paper, forms of renewable energy that could be developed for ILC use will be described, namely, solar energy, wind energy, geothermal energy, hydraulic energy, biomass, and thermal energy obtained from a temperature difference or thermal recovery.

2.Solar cells (photo-voltaic systems: PV systems)

Solar power stations are among the easiest renewable energy systems to build, in contrast to wind power generators and geothermal power stations. However, PV systems are not reliable or stable power sources.

In this paper, we will discuss the solar park for the Green ILC (design date supplied by UNISUN JAPAN). The AC output capacity will be 200MW, and the DC capacity at installation will be 220MW. A similar plant is shown in Fig. 1.

The inverter will be a TMEIC 1500kW (750kW x 2)/unit. TMEIC has the largest market share in Japan at more than 70%, as well as more than half of the global share.

The output voltage will be 22kV, and the solar panels will each generate 265W.

A one (1) MW solar power station requires  $15,000m^2$  of land. The basic design is as follows.

Solar Power F	Plant – Neuhard	enberg 145 MW		
Project Overview		Project Loca	ation	
<ul> <li>The project is one west Europe, locat of 20 MW. The proj</li> <li>The project is deve</li> <li>The EPC contractor</li> </ul>	part of the biggist single f ed in neuhardenberg, Gern ject achieved interconnection loped over 350,000m <sup>2</sup> of fla of 20 MW is Baysolar Proje	<sup>2</sup> V project(145MW) in nany with DC capacity on in September 2012. at land. :kt GmbH.	now-Mogin Mirkische Höhe Reuhindenberg m Gusow-Platko	
Key statistics				
Project Name		Neuhardenberg	South and the second se	And the second s
Location		Jichisu, Romania		
Nominal Capacity	kwp	20,000	States and the state of the sta	
first year's production	Gwh	13.15		
Technology		Poly		
Modules		Talesun		STA STANLES
Inverters		Powador	- AND	
Grid Connection		30-Sep-12		and the second s

Fig. 1 One of the largest solar plants, generating 145MW (Germany) and presented by UNISUN JAPAN.

Required land area:  $15,000 \text{m}^2/\text{MW} \times 220 \text{MW} = 33,000,000 \text{m}^2$  (3,300ha). This area corresponds to dimensions of  $150 \text{m} \times 22,000 \text{m}$  and does not include the 22 kV/154 kV substation and control building.

Array design: 23 panels/string, 6.095kW/string

Solar panel quantity: 220,000kW ÷ 6.095kW/string = 36,095 strings

36,095 strings × 23 panels/string = 830,185 panels (219,999kW)

In the subsequent discussion, the following symbols are used:  $V_{oc}$  (open circuit voltage),  $V_{mp}$  (maximum peak voltage),  $I_{sc}/A$  (short-circuit current), and  $I_{mp}/A$  (maximum peak current).

The reasons for choosing 23 panels/string are as follows, considering that we will use a JA solar JAM6 (BK) 60-265/SI, which has  $V_{oc} = 38.3$ V at 25°C and  $V_{ppm} = 31.1$ V at °C. In the case of 23 series, 984.7V  $< V_{oc} < 1000$ V at -10 °C and 554.2V  $> V_{ppm} > 540$ V at

80°C.

 $3,960 \text{ panels} \div 23 \text{ panels/string} = 172 \text{ strings}$ 

172 strings × 9A ( $I_{sc}/A$ ) = 1,548A

 $1,548A \div 16$  feeders = 96.75A/feeder

Please refer to page 6 of the GO-A5ES-2014-001-A specifications.

The rated current of the power fuse is 160A, and the recommended current is 102A  $(160 \div 1.25 \div 1.25 = 102A)$ , according to NEC690.8 (US electrical STD).

97A < 102A

The actual current is 11 parallel/box  $\times$  15 array boxes + 7 parallel/box = 16 incoming for one 750kW inverter.

 $\therefore 11 \times 9A = 99A$ 

99A < 102A

The required number of inverters is as follows:  $200MW \div 1.5MW$ /inverter = 133 inverters.

Local governments will be essential in building such immense solar parks. These power stations should be built on the ILC grounds by a business partnership, and the land should be supplied by the government for this enterprise. The company will pay taxes as well. In case the land is farmland or is protected forest by law, the local government will provide the necessary documentation and change the land category so that the power station can be built.

All of the generated power will be consumed by the ILC, and therefore no transmission capacity issues will occur. Tohoku-epco claimed that solar power will overflow sooner or later; however, their estimate assumed that all solar parks approved by the Ministry of Economy, Trade and Industry (METI) would generate power.

All of the nuclear power stations (NPSs) shown in Table 1 are operable. METI estimates that only 40% of approved solar parks will actually be commissioned, while the other 60% will be given up for some reason. The NPSs in Table 1 are all boiling water reactors (BWRs), which is same type of NPS as the Fukushima Daiichi NPS. Furthermore, some of them are very old, and therefore it would be quite unlikely for them all to be simultaneously operable before they are decommissioned. Thus, it can be concluded that Tohoku-epco's concern is needless.

The key is that local governmental support is necessary for this type of renewable

energy system to be implemented. The land should be free, not only that used for the ILC main body, but also that for the Green ILC power stations. The government will perform all necessary legal work, such as changing forest land or farmland to miscellaneous lands.

As mentioned previously, there are no transmission capacity issues since the ILC will consume all of the generated power.



Table 1. Nuclear power stations related to Tohoku-epco.

Concerning the economics, the feed-in tariff (FIT) price for solar power will be  $\frac{27}{kWh}$  after June in FY2015. The FIT price has decreased from  $\frac{42}{42}$  in 2012 to  $\frac{436}{36}$  in 2013,  $\frac{432}{32}$  in 2014, and  $\frac{429}{29}$  until the end of June this year, after which it will be  $\frac{427}{kWh}$ . In this paper, we will assume  $\frac{420}{kWh}$  as the FIT price. The sunshine time in Iwate Prefecture is 1,888h/year, corresponding to a power generation of 234,110 MWh/year and an output price of 4.7 billion  $\frac{4}{year}$ . The Green ILC utility company will sell all of the power to Tohoku-epco, and about 10% of the income will be donated to the ILC. After the FIT has been paid off, control of the power plant will be transferred to the ILC, and thereafter, the ILC will be able to obtain free electricity for about 1,250 h/year.

The other government support requested of the METI Sendai office is that the licensed electrical engineer will maintain both the ILC and the Green ILC. Since the Fukushima Daiichi NPS disaster, there has been a heavy shortage of licensed electrical engineers.

### 3. Wind power generation

In the early stages of Japanese wind power generation, power stations were constructed by local governments with imported turbines. However, they did not well endure Japanese weather, and almost all were retired. The Japanese weather phenomena and problems that affect wind power are as follows.

- The direction of the wind changes many times per day. For example, there may be sea breezes in the morning and mountain winds in the evening. Furthermore, mountain sides have irregular air flows.
- 2) Wind power generation requires an average wind speed of 6.5m/s. It is quite difficult for humans to live in locations that meet this requirement, so no access roads or transmission lines are available. Thus, utility costs will be high without a generator system. For instance, the Chiba Marine field is famous for its strong winds, and this baseball park has the only wind speed meter in Japan. However, the strong winds that are present at the ball park are not usable for power generations, as the winds that are defined as strong at this location only measure 3–4 m/s according to the wind speed meter. Figure 2 shows the Chiba Lotte Marines field.



Fig. 2 Home ground of Chiba Lotte Marines (QVC Marine field)

- 3) If people live nearby, low-frequency noise must be considered.
- 4) Typhoons and/or tornados generate winds over the design speed.
- 5) In Japan, thunderstorms occur more often than they do in other nations, and lightning may hit the turbine blades.
- The center line of a turbine shaft is located very high (50–100m), making it difficult to maintain and repair.
- Assessments of bird strikes and other environment factors take time (more than three years). Thus, it is difficult to judge whether or not to invest.

Even though there are many difficulties involved in wind power station construction, if locations are available that will yield more than 2MW/unit of power generation and if there is strong support from the local government, it is possible to build such stations. In addition, the FIT of  $\frac{1}{22}$ /kWh will be maintained for 20 years, and according to Tohoku-epco, the peak power times of solar and wind power are different (Graph 1), so both generation systems can use same transmission lines and same locations. Thus, if a 200MW solar park is constructed at the ILC, then 72MW of wind power can be generated also. In this case, one generator unit would yield 6MW, which would be the greatest power generation in the world for a single unit. A total of 12 generator units will be located at the north end of the solar park. It is recommended that the local government study the average and maximum wind speeds at the ILC.



Graph 1. Peak output of solar cell and wind power generation reported by Tohoku-epco.

4.Geothermal power generation

Tohoku-epco and Toshiba explained geothermal power generation in another section of the Green ILC. Please refer to the above documents.

The Ministry of the Environment reported that the potential geothermal power generation is 33,100MW, while the recoverable amount is 14,200MW. This power is 17 times higher than that consumed by the ILC.

The author studied geothermal power generation at Japan Metals and Chemicals Co. Ltd. in Iwate Prefecture as a student 50 years ago. This company has more than 50 years of engineering knowledge and experience related to geothermal power generation.

The geothermal power generation capacity is 100MW in Iwate Prefecture, which is the second largest capacity in Japan. If an additional 100MW of geothermal energy were generated in Iwate, all of the power consumed by the ILC would be provided.

In addition, Japanese geothermal power generation manufacturers are very productive and get 70% of market share of the world. MHI (Fig. 3), Toshiba, and Fuji Electric always compete with one another to be the world's most productive geothermal power manufacturer.



Fig. 3 From MHI Graphic.

5. Hydro-power generation

Hydro-power will be generated at the base load authorized by METI. However, water rights issues appeared when the construction plan was proposed. Thus, local government support will be required.

Here we present the calculations of the energy generated by a 1MW solar power station and the requirements necessary to generate the same amount of energy hydraulically.

The energy generated by a 1MW solar power station is as follows:

1MW × 1,800h/year (insolation time) × 0.6 (ratio of sunshine: from sunrise to sunset) = 1.08GWh.

The construction cost is  $\frac{200,000}{kW}$  (for the solar cells only), yielding a total cost of  $\frac{200,000,000}{200,000}$ .

To achieve the same output by hydro-power:

1.08GWh  $\div$  24h/day  $\div$  365 days/year = 123kW

The hydro-power generation P for a drop H and water volume Q is given by:

 $P (\mathrm{kW}) = 9.8 \times H (\mathrm{m}) \times Q (\mathrm{m}^{3}/\mathrm{s})$ 

In order to achieve 123kW of power generation, if  $Q = 1 \text{ m}^3$ , then *H* will be 12.6m: 123kW =  $9.8 \times 12.6 \text{m} \times 1 \text{m}^3/\text{s}$ .

Considering the efficiencies of turbines and generators, H should be about 14 m. The FIT price will be  $\frac{434}{kWh}$  for 20 years (assuming a total output of not more than 200 kW), yielding a total income of  $\frac{4732,686,400}{4732,686,400}$  over 20 years. Hitachi and Toshiba also have catalogs of mine hydro-power.

### 6. Biomass power generation

MHI developed a biomass plant at the Koiwai ranch in Iwate Prefecture that uses methane gas from dung as fuel (Appendix 1). In addition, MHI and Hakutsuru Japanese Sake Brewing Industry Ltd. are researching how to produce liquid fuel from straws (Appendix 2).

In Japan, biomass generation is currently difficult economically; however, after the commissioning of the ILC, an international scientific project will be operational that will require a sewage treatment plant. Methane gas from this sewage treatment plant could be used as power-generator fuel. Biomass power centers can also produce fertilizer from sludge by using engine waste heat. The FIT for this system is  $\frac{1}{39}$ /kWh for 20 years.

During construction, a great quantity of wooden boxes is generated as waste material. Similarly, forestry necessarily produces large amounts of wooden chips as waste. The best way to use these by-products is as raw material for the paper industry, and there are many paper factories in the Tohoku area. If they do not wish to receive these materials, the second option is to thermally recycle them. In this case, the waste would be used as fuel for boilers, turbines, and generators. This type of system is called a carbon-neutral power station. After construction, such a plant would be a waste-treatment plant for the city. The FIT for such as system ranges from ¥13/kWh to ¥20/kWh for 20 years.

### 7. Temperature-difference energy (waste heat recovery)

The author previously reported that the planned supply of waste heat from the Radioactive Isotope Beam Factory (RIBF) to the next-door 4<sup>th</sup> elementary school in Wako for heating in winter and for swimming pool temperature control was not working,

demonstrating the difficultly of supplying energy outside.

Now we have a new technology, the binary turbine. Turbine systems are being introduced into the market by MHI and other companies. The energy sources will be RF power sources, He compressors, transformers, HVACs, and chillers for water-cooling systems. If the coolant outlet temperature is more than 60°C, and ideally as much as 80°C, electric power generation as well as waste heat recovery can be achieved. For this purpose, teams working on the accelerator and turbine should jointly consider and resolve the differences between the two arguments.

The 200MW electrical consumption of the ILC will be released as heat. If half of that amount can be controlled as waste heat and if the binary turbine system has an efficiency of 40%, the power generated by the turbine system will be 40MW, which is same as the consumption of the ILC control building. Furthermore, this amount is twice as high as RIKEN Wako campus's peak consumption from the utility company, Tokyo Electric Power Corporation (TEPCO).

### 8. Conclusion

The renewable energy sources that can be used in the ILC were explained in this paper. New energy plants cannot be established independently; they require support by local governments and/or utility companies. Without this support, it would be nearly impossible to build the Green ILC in addition to the ILC itself.

Only temperature-difference energy can be controlled by the team at the ILC, but the necessary system is one of most difficult to establish, as reconsideration of the decisions made by the accelerator builders would be required.

Nevertheless, there are numerous energy sources that could be implemented at the Green ILC. Therefore, only the selection of the preferred energy sources and concentration are necessary to realize the Green ILC.

#### 9. Appendix

- 1) Mitsubishi heavy industry graph No.170 2013.1
- 2) Mitsubishi heavy industry graph No.163 2011.

## Power saving and use of New Energy at Riken RI Beam factory (Tadashi Fujinawa, Riken)

#### 1 Introduction

RI Beam Factory (following RIBF) of RIKEN Nishina Center for Accelerator-Based Science (hereinafter RNC) is a heavy ion cyclotron of the top in the world, was commissioned three months earlier than expected in December 2006, the superconducting ring cyclotron (hereinafter SRC) succeeded the initial beam extraction, then, a lot of the research results has been continued to report in various fields.

This time, in the WG of Green ILC where we consider energy saving and new energy, the efforts for the RIKEN of advanced energy-saving technologies are reported, such as the world's first combined heat and power system (CGS) installed in accelerator facility.

#### 2 Co-Generation System

For the introduction of CGS, environmental measures are the largest purpose, as well as Green ILC. When we explained the RIBF plan in RIKEN of the Board, we received a proposition, as physicist, to think something contribution to make "world best accelerator facilities, which, of course, it is specialty of RIKEN accelerator, however, while an accelerator uses electricity and water as if we use public water, something ecology in accelerator, considering about the Kyoto Protocol has been studied." And we, studied various new energy, and concluded that CGS (also referred to as cogeneration) with the introduction of the gas turbine generator (GTG) as the main engine is the best in the RIBF.

In this method, by supplying electricity and heat at the same time, efficiency is greatly improved compared with the supply of electrical only or heat only. The GTG body is shown in Figure 1. Figure 2 photo shows periodic inspections. Figure 3 shows a flow diagram of CGS.



Figure 1 GTG body, and the right side is the compressor, left turbine



Figure 2 during annual inspection, the front is the compressor, rear is turbine



Figure 3 G is the generator, C shows the air compressor and a turbine, by generating saturated steam in the waste heat boiler, making it as a heat source of the absorption chiller cooling to make a cold water of  $7^{\circ}$ C, for the building cooling and the accelerator facility cooling, and is used for the intake-air cooling of the CGS.

This equipment has been introduced as an environmental measure, that is, as a response to the Kyoto Protocol as RIKEN. In fact, it also plays very important role into a function of accelerator facility as a large uninterruptible power supply at the same time.

CGS is using natural gas supplied from the Tokyo gas as fuel, the output of the generator is introduced and consumed in the RNC and the commercial lines of the Tokyo Electric Power Company (TEPCO) in parallel. If a problem in CGS has occurred, power is supplied to all of the accelerator from TEPCO uninterruptible.

If the instantaneous voltage drops (voltage sag) or power failure occurs in TEPCO, CGS disconnect the commercial line within one cycle, CGS provides power only to the critical loads such as helium refrigerator.

We believe that it is previous special situation to drive the accelerator, if the supply of TEPCO and Tokyo Gas will be disabled at the same time.

It should be noted that, for the power shortage due to the Fukushima Daiichi nuclear power plant accident in 2011, RIKEN CGS contributed to power supply to perform continuous operation until the end of the year.

For more information, accompanying CGS, you should refer the article in "accelerator" Vol.8, No.1, 2011(18-25) and "consideration of the large accelerator facilities for combined heat and power device as an uninterruptible power supply - RIKEN CGS-"<sup>1)</sup>.

For English article should be referred to a Proceedings<sup>2)</sup> of ARW2013 and "RIKEN Accelerator Progress Report 36. (2003) ", "Cogeneration system for RI Beam Factory<sup>3)</sup> ", Report 37 (2004) CGS operation<sup>4)</sup>.

Finally, as for the environmental effect, maximum efficiency is proud of the 68%, because the generator is located directly above the accelerator, there is no transmission loss. Natural gas is a very clean fuel compared to coal and oil. CGS absorption refrigerator is different from the typical refrigerator to repeat the compression-expansion by using a motor, there is an advantage of not using any ozone-depleting gas or greenhouse gases.

#### 3. Energy saving and environment effect other than the CGS

It was already mentioned that minimization of transmission loss by placing the CGS just above the accelerator facilities. For commercial lines from TEPCO, the second special high voltage substation (the second extra-high voltage) was constructed at the top of the accelerator building, connected the 66kV underground line by the full-length 750 m from the first extra-high voltage substation in order to reduce the transmission loss. In the first floor basement, place the power supply room 2 to transform the high voltage (6.6kV) to low voltage (415, 220, 110V), further down below the power room 1 which houses the accelerator power was placed, in the next to the power room 1 the accelerator was arranged, in this way, the cable length was minimized.

In addition, high-voltage AC power supply of the experimental equipment SHARAQ (1MVA) and Rare-RI Ring (R3) 1.5MVA deployed to the accelerator room, with an effort to minimize the low-voltage cable length.

In the accelerator facilities, a lot of the electric motor in the cooling system being used, it is kept in mind the energy saving using a high efficiency electric motor actively.

It shows a photograph of a high-efficiency motor in Figure 4. Ordinary efficiency of the electric motor has a warship color in any manufacturer, gold color motor in the photo is made of Toshiba, a black color motor by Fuji Electric, they are descriptive.
Mitsubishi has two color motor, 31th US Navy warship color of GSI Creos Mr. HOBBY is high efficiency, 32th Japan Navy color (Yokosuka) is ordinary efficiency, to be difficult to determine the type. We suspect that there is a length of day advance in Toshiba and Fuji.



Figure 4 high-efficiency motors that are used in the cooling system (Toshiba)

Direct drive method was adopted for the motor start-up scheme considering helium compressor (315kW) as a main system, is a good start method for efficiency compared with the other start-up method (reactor, compared to Y-  $\triangle$  and inverter start-up).

High efficiency high/low voltage transformer is also adopted. Efficiency of the transformer are also advances year by year, the latest of a transformer for the RNC is the 99.4% of R3 (at rated 1.5MVA).

In addition, the transformer there is no worry of fire by using a dry-type transformers. As a result, carbon dioxide fire extinguishing equipment which has a risk of death is no longer needed. As harmonic voltage measures, we arranged the transformer alternately the winding  $\triangle - \triangle$  and the  $\triangle -Y$ , so as to obtain the same effect as three winding transformer. In CGS central control room, there is a harmonic monitoring device, and always shows the minimum value of the measurement limit. This is also that environment friendly design.

For more information, please refer to the English article <sup>5) 6)</sup>.

#### 4. New energy other not adopted

1) Solar cell: As the simplest new energy, solar power generation is raised. Since the energy density is low (a large area required), Wako of sunshine time is 1840 hours per year, even side-by-side solar cells on the existing Nishina Memorial Building roof, power generation capacity of about 40kW the maximum, there is unreasonable as the accelerator power. However, as a whole RIKEN, five places at the moment, we have total a 120kW of equipment. All generated power is a self-consumption, does not use fixed-price purchase system.

2) Wind power generation: suitable wind speed for wind power generation is 6 m per second, while average wind speed of Wako City is the 1 m. So it is not at all adapted.

3) Adsorption chillers: by changing the cooling water output temperature of the accelerator from 60 to  $80^{\circ}$ C, and making it as a heat source of the adsorption-type refrigerator, to give the cold water of 7°C to be used for the air conditioning and cooling. As accelerator side, there is anxiety that the cooling water temperature is high, so we gave up.

4) Temperature difference energy<sup>7)</sup>: those are proposed in Wako City area new energy development committee, that waste heat of RIBF the (around 40°C), supplied to adjacent the Wako municipal fourth elementary school, for heating, hot water supply, and pool. It has been favorite proposal benefit to Wako areas as a result of the study over two years, however, a business entity did not appear, and did not reach to a realization, together with a problem of the education committee.

For more details, refer to the English documents.

### 5. Application to the ILC

High-efficiency equipment (electric motor, transformer, etc.) and so on, should be introduced for granted. It is necessary to note that it is slightly different even in the same high efficiency number by the manufacturer.

Next, as for the electric transmission and distribution, therefore it is very important and is described in a separate description. Please refer there.

Adsorption chillers with good improvement for performance in recent years, and worth considering because also possible to operate at a lower temperature.

CGS is an energy saving of the centerpiece of RIBF, but here it is necessary to pay attention.

The first, in planned construction site, there is no city gas, that is to lay the pressure pipe for CGS is required huge cost. In the case of RIKEN, because there was a medium pressure pipe next to the site of RIBF, so it was realized. Even if temporarily it is solved the problem of gas piping, because the ILC using 10 times the electricity of RIBF, by simply thinking, it requires 65MW of engine. For the gas engine it is too large, for the latest of composite power generation GTG it is too small.

Furthermore, absorption chiller which is key component of CGS has no noticeable progress in this more than 10 years. On the other hand, COP (Coefficient of Performance) of the motor drive refrigerators improving to 3 or more in the hot water supply, up to 6 or more in cooling, rather than a combined heat and power, combined cycle power generation (Combined Cycle; CC) can be used to convert to electricity, then to carry out the cooling and heating by the converted electricity. Those efficiency is good in the final end.

Temperature difference energy, it is to find a business entity who can build firstly with the investment.

1) "accelerator" Vol.8, No.1,2011 (18-25) record and consideration of the large accelerator facilities for combined heat and power device as an uninterruptible power supply - RIKEN RIBF of CGS-

2) ARW2013. Proceedings

3) RIKEN Accelerator Progress Report 36. (2003) Cogeneration system for RI Beam Factory

4) Report 37 (2004) CGS operation

5) WAO07. DESIGN, INSTALLATION, OPERATION AND MAINTENANCE OF ELECTRICAL POWER SUPPLY FOR RI BEAM FACTORY

6) RIKEN Accelerator Progress Report 46 (2013) AC power system for Rare-RI Ring.

7) New Energy Establishment Committee of Wako City District and RIBF; RIKEN Accelerator Progress Report

<sup>6.</sup> Reference





Solar Power (Junichi Honda, Solar Power Association and Kyocera)

























## Biomass power generation using ILC exhaust heat (Mituo Takeda, Kabuki, Hitachi-cement, Nihon-premium, Mizuing)

#### 1. Introduction

Since International Linear Collider: ILC, become one of the foundation industry for the region, it will be intended to integrate to regional management unification. If the facility is operational once, a number of researchers and their families from abroad will visit and stay, then how the effective use of the waste generated from there is a theme as a national project. Furthermore, it is considered necessary to indicate the way of next generation waste disposal incorporation with the entire region is developed.

By operating the linear accelerator of 30km or more as the main ILC facilities, a large amount of heat is generated. By utilizing the exhaust heat, it is possible to ensure the thermal energy source, which accounts for significant costs in organic waste treatment at low cost. Biomass power generation, although a wide variety of methods have been taken, as simple as possible is good, by using an inexpensive heat, direct combustion power plants which accept any type of organic waste are proven, and can be expected.

2. Biomass direct combustion power generation plant

(1) the value of biomass direct combustion power generation plant

 $\cdot$  It is possible to generate electricity by using animal and vegetable waste generated in the region.

- By using the waste heat of the ILC facility, it is possible to dry them with costs cheaper

- Along with the drying  $\rightarrow$  incineration  $\rightarrow$  power generation is simple line, also accepted any kind of organic waste.

And disposal destination of sewage sludge and organic waste will expand.

- Reduction of the incineration plant of each municipality is measurably proceed.

(2) flow of direct combustion power plant

In biomass direct combustion power plant flow as shown in Figure 1, it is to accept all of the biomass from the high moisture content livestock manure to as low as rice straw, is to dry by the ILC exhaust heat and recovered heat. Then burned directly, and then the power generation by the steam, use the full generated power at the ILC facilities.



Figure 1 biomass direct combustion power generation plant flow

(3) Considerations of direct combustion power plant

<Notes of dry>

 $\cdot$  For drying machine, the rotary dryer type is safe to cope with the wide variety of biomass.

 $\cdot$  When the oxygen concentration is high, it is necessary to lower the oxygen concentration replaced with steam (turbine extraction steam) and the exhaust gases, since there is likely to be burned in a dryer.

 $\cdot$  In order to keep the dry exhaust as much as possible, it will be exhausting and dehumidified in the wet scrubber, re-heating by the ILC recovered heat, and recycling and re-using some part.

 $\cdot$  Surplus exhaust, you can either use as combustion air of incinerator, or on the deodorizing process, then dissipated to the atmosphere.

<Incinerator type>

 $\cdot$  By taking into account the nature, input amount, fluctuation range of input, the optimum furnace type should be selected from stoker, fluidized bed, and the other.

 $\cdot$  Review of the post-process of the exhaust gas treatment.

3. Power generation amount expected by biomass direct combustion

(1) Biomass endowment amount and effectiveness available amount

In the Tohoku region (Iwate, Miyagi Prefecture) and Kyushu region (Saga, Fukuoka Prefecture), each of the biomass endowment amount and effectiveness available amount can be estimated from NEDO data, as shown in Table 1.

		林地列	浅材	切り捨て	【間伐材	果樹剪定材		タケ		稲作残渣・稲わら		
			有効利用可能量 DW-t/年	有効利用熱量 GJ/年	有効利用可能 量DW-t/年	有効利用熱量 GJ/年	有効利用可能 量DW-t/年	有効利用熱量 GJ/年	有効利用可能 量DW-t/年	有効利用熱量 GJ/年	有効利用可能 量DW-t/年	有効利用熱量 GJ/年
東地	東北	岩手県	4,980	90,142	5,982	127,390	5,214	59,956	1,475	18,432	39,315	534,690
	地区	宮城県	1,316	24,627	2,167	46,155	3,117	35,847	4,644	58,055	51,075	694,617
	九州	佐賀県	746	13,495	477	10,148	7,733	88,935	17,311	216,383	18,752	255,031
	地区	福岡県	402	7,282	1,757	37,423	12,614	145,056	29,999	374,992	27,493	373,900
			稲作残渣·籾殻		麦わら		その他の農業残渣		<del>+</del>			
			有効利用可能量 DW-+/在	有効利用熱量 GJ/年	有効利用可能 量DW-+/年	有効利用熱量 Gul/年	有効利用可能 量DW-t/年	有効利用熱量 G1/年	有効利用可能 量DW-t/年	有効利用熱量	有効利用可能 量DW-t/年	有効利用熱量 Gul/年
	亩北	岩手県	4,790	68,022	1,444	19,638	9,455	102,111	2,417	32,876	135,516	1,843,020
	地区	宮城県	5,416	76,909	971	13,208	9,146	98,779	0	0	28,703	390,362
	力,州	佐賀県	2,309	32,791	8,109	110,288	12,201	131,770	54	738	3,998	54,367
	地区	福岡県	4,504	63,962	7,706	104,805	8,079	87,249	18	239	27,714	376,913
[		国府材制封函封		人力制力感力		建筑南封		新• 逆壅 庵材		公園前完技		
			有効利用可能量	有効利用熱量	有効利用可能	有効利用熱量	有効利用可能	有効利用熱量	有効利用可能	有効利用熱量	有効利用可能	有効利用熱量
	ᆂᆘ	岩手県	12,459	225,502	重DW-t/年 2,699	48,846	重DW-t/年 2,742	49,625	重DW-t/年 2,467	44,659	重DW-t/年 14,815	87,487
	<sup>宋 11</sup> 地区	宮城県	6,154	111,394	4,462	80,109	10,114	183,068	725	13,117	2,652	30,503
	九州	佐賀県	1,640	29,683	162	2,938	3,896	70,511	291	5,266	611	7,022
	地区	福岡県	1,547	27,996	1,045	18,919	4,007	72,535	2,246	40,650	3,562	40,965

Table 1 Biomass endowment amount and effectiveness available amount

		乳用牛糞尿		肉用牛糞尿		ぶた糞尿		採卵鶏糞尿		ブロイラー糞尿	
		有効利用可能量 DW-t/年	有効利用熱量GJ/年	有効利用可能 量DW-t/年	有効利用熱量GJ/年	有効利用可能 量DW-t/年	有効利用熱量GJ/年	有効利用可能 量DW-t/年	有効利用熱量GJ/年	有効利用可能 量DW-t/年	有効利用熱量GJ/年
東北	岩手県	6,642	39,690	14,815	87,487	6,642	39,690	2,847	32,739	13,686	223,060
地区	宮城県	5,578	32,132	13,198	77,927	3,973	23,750	1,262	14,505	1,096	17,866
九州	佐賀県	1,133	6,521	8,581	50,669	1,582	9,449	467	5,364	2,489	40,560
地区	福岡県	4,112	23,683	3,382	19,977	1,077	6,443	3,706	42,624	524	8,523

-											
		下水汚泥(濃縮汚泥)		し尿浄化槽・余剰汚泥		集落汚水汚泥		食品加工廃棄物		家庭系厨芥類	
		有効利用可能量 DW-t/年	有効利用熱量 GJ/年	有効利用可能 量DW-t/年	有効利用熱量 GJ/年	有効利用可能 量DW-t/年	有効利用熱量 GJ/年	有効利用可能 量DW-t/年	有効利用熱量 GJ/年	有効利用可能 量DW-t/年	有効利用熱量 GJ/年
東北	岩手県	680	6,046	309	2,992	623	6,297	200	576	18,311	373,577
地区	宮城県	0	0	241	2,332	463	4,678	4,400	12,672	34,234	698,455
九州	佐賀県	0	0	372	3,602	190	1,922	2,561	7,374	11,744	239,609
地区	福岡県	3,562	31,687	818	7,920	142	1,437	1,800	5,184	69,199	1,411,822

-				
		事業系厨芥類		* バイオマス推計方法の定義
		有効利田可能	有効利田執景	(1)賦存量
		量DW-t/年	GJ/年	賦存量は、バイオマスの利用の可否に関わらず理論上1年間に発生、排出される
■十	岩手県	7,567	154,388	量とした。なお、本定義によらないものは個別に定義してた。
州区		成県 14,740		(2)有効利用可能量
	宮城県		300,728	有効利用可能量とは、賦存量よりエネルギー利用、堆肥、農地還元利用等、既に
九州	佐賀県	4,922	100,427	利用されている量を除き、さらに収集等にに関する経済性を考慮した量を利用可能 量とした。
地区	垣岡順	四月 21.011 622.70		(3)熱量
	111回乐	31,011	032,700	賦存量と有効利用可能量について、熱量の推計を行った。熱量はバイオマス種に より直接燃焼またはメタン発酵により発生するメタンの熱量として算出を行った。

Summarizing the results, the number are shown in Table 2.

		有効利用可能量DW-t/年	有効利用熱量GJ/年		
= 사 차 다	岩手県	318,092	4,279,248		
朱北地区	宮城県	209,847	3,041,795		
計	-	527,939	7,321,043		
누 에 해요.	佐賀県	112,331	1,488,343		
767117012	福岡県	252,026	3,964,889		
計	-	364,357	5,453,232		

Table 2Summary table

(2) The expected amount of power generation from biomass direct combustion

After calculating the total amount of heat per year from each of the effective use possible amount of both regions,

Tohoku district: 7,321,043GJ/year ≒ 2,033,623,055kwh

Kyushu district: 5,453,232GJ/year ≒ 1,514,786,650kwh

Power generation amount in the case of use all the effective utilization heat quantity by the efficiency 20% of the power generation system,

Tohoku district: 2,033,623,055kwh × 0.2 = 406,724,611kwh

Kyushu district: 1,514,786,650kwh × 0.2 = 302,957,330kwh

Output in the case of the power generation equipment that runs the power generation per year 7,000 hours,

Tohoku district: 406,724,611kwh ÷ 7,000h = 58,104kw

Kyushu district: 302,957,330kwh ÷ 7,000h = 43,280kw

When there is an effective available amount of about 10 to 20%, it can be expected that the following output.

Tohoku district: 58,104kw ×  $10 \sim 20\% = 6,000 \sim 10,000$ kw Kyushu district: 43,280kw ×  $10 \sim 20\% = 5,000 \sim 10,000$ kw (3) Amount of heat required for biomass fuel drying

Required amount of heat to dry the biomass waste, is calculated as follows.

① Effective available capacity

If drying the moisture content from  $60\% \rightarrow 15\%$ , water evaporation amount W is,

W = effective use possible amount × (1- solids ratio before drying / solids ratio dried) Tohoku district W =  $527,939t/year \times (1-40\% / 85\%) = 279,497t-H_2O/year$ 

Kyushu W =  $364,357t/year \times (1-40\% / 85\%) = 192,895t-H_2O/year$ 

<sup>(2)</sup> The necessary amount of heat to dry

Latent heat of vaporization at  $70^{\circ}$ C (qj) = 2,332kJ/kg, and the drying efficiency (n) = 60%.

 $q = W \times qj / n$ 

Tohoku district q =  $237,572 \times 2,332 / 0.6 = 924$ GJ/year

Kyushu district q =  $192,895 \times 2,332 / 0.6 = 750$ GJ/year

3 If you have 10 to about 20% of the effective possible amount of use

Tohoku district 924GJ/year  $\times$  10  $\sim$  20% = 100  $\sim$  200GJ/year

Kyushu district 750GJ/year  $\times$  10  $\sim$  20% = 75  $\sim$  150GJ/year

4. Challenges for biomass direct combustion power generation

(1) Collection challenges

· How much ensured biomass collection amount is, from location issues?

· It was assumed 10 to about 20% of the effective use possible amount, as a planning.

· Local understanding can be obtained in broad-based way?

(2) Issues of plant installation

· ILC facility adjacent is favor, but challenges such as landscape and smell issue remain.

· Whether it is possible to underground plant including the cost?

 $\cdot$  What is extent of temperature, amount, operating time, and period of the tunnel exhaust heat?

· Recycling of incinerator ash? or final disposal method?

## 5. Reference Case (Hitachi cement) Biomass methane fermentation plant



This project, has large part at the joint venture with local governments and the private sector, in a sense might also say PPP (Public Private Partnership) civil cooperation. There is a need to local governments to be a prerequisite to gain certification of Biomass Town, confirmation of intention is important (Figure 2).



Figure 2 Tsuchiura Biomass Town Initiative

(1) Overview of biomass utilization business

Framework of the business is as follows, the gas by methane processing mainly from food waste (general waste, industrial waste) is used as a co-combustion gas of the cement burning fuel. Further it features a composting facility, by utilizing a part of, such as digestion solution from the methanation facility, perform the manufacture and sale of compost (Figure 3). In this project, there is also a merit of burden reduction, such as a reduction in the size of the incinerator, in local government.

As for business scale, it becomes 100t/day of methane gas reduction facility, and 30t/day composting facility.

The facility of summary flow is shown in Figure 4. By acceptance of garbage, animal and plant residues in biomass in the building, after removal of the fermentation unsuitable material at fracture separation, it is fed to the methane fermentation tank through the solubilization, anaerobic fermentation process is performed.

Biogas obtained by methane fermentation process, is used as auxiliary fuel substitute of the existing incineration facilities, also makes use of the surplus steam boilers of the existing incineration facility as a heat source of the methane fermentation tank and dryer of the new plan facility.

Digestion solution after methane fermentation is to solid-liquid separation at the dehydrator. Dehydration residue is subjected to aerobic fermentation process in the later stage of fermentation composting facility, to provide compost to the regional farmers and citizens. Filtrate after dehydration processed by water treatment to the sewage discharge standards, then it will be discharged into the sewer.



Figure 3 framework of business



Figure 4 the processing flow of methane gas

## Geo-thermal Power Generation System using variety of under-ground energy (Toru Shibagaki, Toshiba)



















## Summary of Geo-thermal power generation of Tohoku Electric Power (Kentaro Otuki, Tohoku Electric Power)

1. Mechanism and characteristics of geothermal power

o Mechanism of geothermal power generation

The steam of low temperature that has finished work in a steam turbine becomes condensed water in the condenser, is back from the reinjection wells in the basement. (Figure 1)



Figure 1 mechanism of geothermal power generation

• Features of geothermal power generation

Features of geothermal power generation is as follows.

- Net domestic energy that does not rely on imports
- Renewable energy
- Stable power supply in the natural energy
- Environmental load is small, CO<sub>2</sub> emissions is small
- Multi-purpose use is possible (agriculture, forestry and fisheries, tourism, etc.)
- Share is not very large in the world

Life cycle CO<sub>2</sub> emissions of geothermal power generation has become a low level

compared to other power sources.

Also, compared to other renewable energies, as high as about 80% facility usable rate, there are many power generation can be characterized by the same output. (Figure 2)



<Source> Federation of Electric Power Companies of Japan, "Nuclear energy drawings collection 2014"<<p>□ 電源別の設備利用率

地熱	約80%
風力	約20%
太陽光	約12%

#### <出典>コスト等検証委員会報告書 (内閣府:平成23年12月19日)

Figure 2 life cycle CO<sub>2</sub> emissions, each power supply facility usable ratio

2. World and Japan's geothermal power generation

• History of geothermal power generation

1904 Driving a generator using natural steam by Jiriko Conti Duke in Italy Larderello (output 0.75 hp)

1913 The world's first geothermal power plant in Italy Larderello (output 250kW)

1918 Vice Admiral Toshiharu Yamauchi started excavation at Oita Prefecture Hayami District Asahi village Tsurumi 950-1. The success of excavation in 1919. (Pore size 4 suns, depth 80 shaku)

1925 Mr. Osamu Tachikawa of Tokyo electric light Ltd. Institute, took over the business

of Yamauchi et al, named "Tsurumi fumaroles", after number of test results, the first successful geothermal power generation in Japan by the turbine. (Output 1.12kW)

1947 Geological survey was started for research on the selection of geothermal development area.

1948 Tone bowling Ltd. succeeded in power generation by steam turbine in Shizuoka Prefecture Joto village Yunosawa laboratory. (3kW)

1951 The geothermal power generation succeeded in Industry and Technology Agency Beppu test site. (Output 30kW)

1958 The world's first start of operation of geothermal power plants in hot water separation type in New Zealand Wairakei. (Output 6,500kW)

1960 Start of operation of private geothermal power generation at Fujita Kanko Inc. Hakone Kowakien. (Output 30kW, 1965 obsolete)

1966 Start a geothermal power generation by Japan Metals & Chemicals Co., Ltd. At Matsukawa geothermal power plant at the first time in Japan. (Output 9,500kW)

1967 Start a geothermal power generation by Kyushu Electric Power Co., Ltd. At Otake power plant. (Hot water separation type, output 11,000kW)

1996 Geothermal power output 500 000 kW achieved.

2006 Japan's first binary power plant (Hatchobaru, 2,000kW) was in operation.

2012 feed-in tariff (FIT) was started.

• Geothermal power generation facilities in the world

Japan is located in the volcanic zone of the Pacific Rim, abundance of geothermal is said to be third largest after the United States, and Indonesia, however, the introduction amount is not as many than other countries. (Figure 3, Figure 4)



<Source> National Institute of Oil, Gas and metal mineral resources mechanism "geothermal pamphlet"





<Source> National Institute of Oil, Gas and metal mineral resources mechanism "geothermal pamphlet"

# Figure 4 World major geothermal resource amount of each country, and the change in the geothermal power generation capacity

o situation of geothermal development in the world

Geothermal development in countries around the world is accelerating aggressively. (Figure 5)

単位:万kW

业国	2005年	2010年	2015年(見込み)							
不国	256.4	309.3	540							
(注)主な地熱発電所:ガイザーズ(カリフォルニア州、14基、出力127.3万kW)等										
ハドナシア	2005年	2010年	2015年(見込み)							
コントインプ	79.7	119.7	350							
(注)主な地熱発電所:サラク(西ジャワ州、6基、出力37.5万kW)等										
	2005年	2010年	2015年(見込み)							
ニュージーランド	<u>2005年</u> 43.5	<u>2010年</u> 62.8	2015年(見込み) 124							
ニュージーランド	2005年 43.5 (注)主な地熱発電所:タウオ	2010年 62.8 ポ(ニュージーランド北島、11ま	2015年(見込み) 124 ま、出カ17.5万kW)等							
ニュージーランド	2005年   43.5   (注)主な地熱発電所:タウオ   2005年	2010年 <u>62.8</u> (ニュージーランド北島、11ま 2010年	2015年(見込み) 124 ま、出カ17.5万kW)等 2015年(見込み)							
ニュージーランド	2005年   43.5   (注)主な地熱発電所:タウホ   2005年   20.2	2010年 62.8 ポ(ニュージーランド北島、11ま 2010年 57.5	2015年(見込み) 124 <sup>ま、出力17.5万kW)等</sup> 2015年(見込み) 80							

<出典> Ruggero Bertani : Geothermal power generation in the world 2005-2010 update report

Figure 5 status of the world's geothermal development

3. The proportion of power generation scale of nationwide and our company

• Power configuration ratio based on power generation capacity

As for our company's geothermal power generation, it is about 1% of power generation installed capacity in our company inside, and it is a minority and less than 1% in Japan. (Figure 6)





Figure 6 Power supply configuration ratio in accordance with power generation installed capacity (nationwide, our company)

• Power generation scale of geothermal power

Currently, geothermal power generation in Japan has been developed in the17 points, most of which have been installed in the Tohoku and Kyushu. (Figure 7)



	全国	東北電力
地点数	17地点	5地点
認可出力 (万kW)	51. 509	24.730 (48%)
発電電力量 (億kWh)	26. 2	10. 3 (39%)

<Source> geothermal power generation of the current status and trends 2013

<Source> "Japan's geothermal power plant" Industrial Scienc and Technology Institute HP

Figure 7 Japan's geothermal power plant and the power generation amount

4. Features and efforts of our geothermal power

o Overview of the geothermal power plant of our company

Our Company has 5 power plant 6 generators including a cooperating group, total authorized output accounts for about 48% of the geothermal power plant of Japan. (Figure 8)

Our company's (including a group of companies) geothermal power plants are, relatively, located in the vicinity of the ILC candidate site. (Figure 9)

発電所名	所在地	号機	設備容量 (kW)	運転開始	蒸気供給会社
葛根田	岩手県雫石町	1号	50,000	S53.5.26	<b>東北水力地熱(株)</b> (旧)日本重化学工業
		25	30,000	H8.3.1	
上の岱	秋田県湯沢市	_	28,800	H6.3.4	東北水力地熱(株) (旧)秋田地熱エネルギー
澄川	秋田県鹿角市	-	50,000	H7.3.2	三菱マテリアル(株)
柳津西山	福島県柳津町	-	65,000	H7.5.25	奥会津 <b>地熱</b> ㈱
	小 計		223,800		
松川	岩手県八幡平市	-	23,500	S41.10.8	東北水力地熱(株)
	合 計		247,300		

	~ ~		0.1	~				
Liguro	21	Unrunnu	of tha	Compon	v'a i	goothormol	nouvor	aanaratian
LIZUIC	00			Comban	v 5 1	econicimai	DOWEL	2CHCI allOH
					J~ 4			0



Figure 9 position of the geothermal power plant of the Company (including a group of companies)

 $\circ$  Our geothermal power generation organization

The steam production and reduction are conducted by steam supply company. We adopted a joint development system for generating electric power by purchasing the steam (about Matsukawa, consistently operated by Tohoku Hydropower Geothermal Co., Ltd. [group of companies]). (Figure 10)

\* Matsukawa geothermal power plant, consistently operated by Tohoku Hydropower Geothermal Co., Ltd. (group of companies)



Figure 10 Our company's geothermal power generation organization

 $\circ$  Features of our geothermal power plant

Geothermal power plants have a simple structure without such a boiler compared to thermal power plants.

From this reason, we have adopted the remote operating system to monitor and control in the monitoring room of 10-30 km away from each geothermal power plant.

Our company has proceeded further rationalization from 2000 fiscal year, to employ a centralized monitoring and controlling of 5 geothermal power generators of four power plants locations from Akita thermal power plants. (Figure 11, Figure 12)



Figure 11 centralized remote monitor control system



Figure 12 Overview of centralized remote monitor control system

## • Changes in year average output

Our geothermal power plants, there is a high performance experience, after the operation of Kakkonda Unit 1 (1978). In 1990 or later, we have sequentially started the operation of Uenotai, Sumikawa, Yanaizu-Nishiyama, and Kakkonda No.2. Initially,

although the output power was the order of 70-80 percent in about 5-10 years, and significant vapor reduction was happened in 10 years passed, and the output power became about 50 percent in about 15 years and now. After that, it is almost stable at this level.

As annual average output (red line) is close to approval output (blue line), it shows a high investment performance. (Figure 13)



Figure 13 Trends in year average output

 $\circ$  Transition of power generation time utilization

Transition of power generation time utilization ratio of each power plant can be divided to two groups; Uenotai and Sumikawa of high utilization (70-90 percent) group even 15 years after the start of operation, and Kakkonda, Yanaizu-Nishiyama and Matsukawa of low utilization (50% or less) group. You can see the difference in investment performance point by point. (Figure 14)

The power generation time utilization ratio is the percentage ratio of the amount of power generated during the fiscal year, with the amount of power that can be obtained within the actual power generation time at the rated output.



Figure 14 Transition of power generation time utilization ratio

• Challenge of geothermal power plant operation

"Steam well attenuation", "scale", and "hydrogen sulfide" are the issues as big factors that reduce the output (operating ratio) in geothermal power plant operations. Our company has implemented for the operating rate improvement efforts.

• Operating ratio improvement efforts

In Uenotai and Sumikawa geothermal power plant of our company, it has gained a certain degree of success by drilled the replenishment well into the natural park, by receiving benefits of a deregulation of Japan. (Figure 15, Figure 16)



Figure 15 the example of Uenotai thermal power plant replenishment well T-56



Figure 16 The situation of fumaroles of inclination well in the National Monument Park (replenishment production well T-56)

 $\circ$  Geothermal reservoir recharge project

There is a case that the power generation output is fluctuating in a geothermal power plant by being unable to collect the required amount of steam and hot water stably.

By performing the supply of water to the heat source of the underground more appropriately, JOGMEC (National Institute of Oil, Gas and metal mineral resources) is developing a technology to achieve optimization and stabilization of the collected amount of steam and hot water at Yanaizu-Nishiyama geothermal power plant. (Figure 17)



Figure 17 Schematic of geothermal reservoir recharge project

- 5. Challenges and the Japan's support system for geothermal power generation
- Challenges geothermal power generation
- · Single machine capacity is small.

In business power generation facilities in Japan, 3,300kW ~ 65,000kW In Japan of private power generation 100kW ~ 23,500kW

· Research ~ development ~ commercial operation take time.
National-wide survey  $\sim$  wide area survey  $\sim$  rough survey  $\sim$  fine survey  $\sim$  development survey  $\sim$  power plant construction.

(Example: on Uenotai took 23 years)

· Number of new power plant construction is limited.

Since promising areas are unevenly distributed in the Tohoku and Kyushu, and since about half of the possible development area are located in a special area on the Natural Parks Law, new development is difficult.

• For support measures in geothermal development process

Auxiliary support of Japan related to geothermal development (JOGMEC) has been provided in stages. (Figure 18)



<Source> Agency for Natural Resources and Energy, "the current state of geothermal resources development (September 2014)."

Figure 18 Support measures in geothermal development process

o Geothermal development point of nationwide

Figure 19, is a situation of geothermal development sites nationwide.

We in the corporate group are being carried out the early stages of the investigation "Kijiyama - Shimonotai (Akita Prefecture Yuzawa City) area".



<Source> Agency for Natural Resources and Energy, "the current state of geothermal resources development (September 2014)."

Figure 19 status of geothermal development sites nationwide

• Geothermal power plant that was operating since FIT

The operational geothermal power generation facilities after FIT (feed-in tariffs) were five plants and total output of about 250kW. At the moment it is mostly small-scale plant. (Figure 20)



Figure 20 geothermal power plant that has operated since FIT

6. Efforts to geothermal development of our company's corporate group

o Kijiyama, Shimonotai regional geothermal resource development research projects

Our group of companies "Tohoku Hydropower Geothermal" is making the geothermal resource survey of the early stages, in the adjacent land of Uenotai thermal power plant "Kijiyama, Shimonotai".

In the area of Kijiyama and Shimonotai, up to now, we conducted the ground survey, exploration well two, and monitoring well single drilling, then make ongoing the overall analysis. (Figure 21, Figure 22)



Figure 21 bird's-eye view of Kijiyama, Shimonotai area



Figure 22 Kijiyama-Shimonotai regional position

 $\circ$  Kijiyama, Shimonotai region geothermal development research results and planning

Kijiyama - Shimonotai survey schedule is below.

Continues a similar survey to 2015 fiscal year, and to review and evaluate the commercialization potential on it, is expected to plan an investigation after the 2016 fiscal year. (Figure 23)

年度	H22	H23	H24	H25	H26	H27	
調 査 位置づけ	地熱構造調査	地熱構造 モデル作成	地熱構造 モデル見直し	地賞構造調査・モニタリングデータ収集			
地表調査 坑井掘削 他	<ul> <li>地質調査</li> <li>地化架査</li> <li>電力探査</li> <li>坑井沢方</li> <li>、北邦ア方</li> <li>・温泉変動</li> <li>モリンク</li> <li>・微小地震</li> <li>観測</li> </ul>	- 電磁探査 - 自然電位探査 - フラクチャ 解析 - 坑井圧力 モリンパ - 温泉変動 モリンパ - 微小地震観測	- 電磁探査 - 坑井圧力 モニタリング - 温泉変動 モニタリング - 微小地震観測	<ul> <li>坑井圧力</li> <li>モシリンク・</li> <li>構造試錐井</li> <li>掘削</li> <li>温泉モニタリンク・</li> <li>井掘削</li> <li>温泉変動モニタ</li> <li>リンク・他</li> </ul>	・坑井圧力 モニタリンク・ ・構造試錐井 掘削 ・トレーサー試験	<ul> <li>・坑井圧力 モリック</li> <li>・隣接貯留層 との関係評 価他</li> <li>・事業化可能</li> <li>性の検討</li> </ul>	

Figure 23 Kijiyama, Shimonotai investigation schedule

## 7. Utilization of geothermal energy

• Effective utilization of geothermal energy due to the difference in the temperature

We are utilizing the area of the steam power generation, but in recent years has spread the movement to take advantage of geothermal resources in the binary power generation. (Figure 24)



<Source> New Energy Foundation brochure Figure 24 Geothermal energy area and the availability

• Mechanism of geothermal binary power generation (hot spring power generation)

Binary power generation is a system for generating electricity by turning a turbine generator, using a medium having a lower boiling point than water boiled in hot spring of heat ( $70^{\circ}C \sim 150^{\circ}C$ ). (Figure 25)

If the order of several hundred kW is required, it is possible to develop in a short period of about 2-3 years.



<Source> Agency for Natural Resources and Energy, "the current state of geothermal resources development (September 2014)."

Figure 25 mechanism of geothermal binary power generation

• Case Study of geothermal resources

Matsukawa geothermal power plant (Tohoku Hydropower Geothermal Co., Ltd., Iwate Prefecture Hachimantai) warmed condensed water after power generation by the addition of steam, and sold to Hachimantai Industrial Promotion of the third sector. It has been used in Hotels and cottage villa, and in greenhouses with a hot water supply contract. (Figure 26)

(In the 2010 fiscal year, 70 °C, up to 260t/h)

		供給先			
・ホテル等	38軒	・保養所	25軒	・別荘	613軒
・商店	15軒	・貸別荘施設	1軒	・病院	1 軒
・老人ホーム	1軒	・日帰り温泉施設	1軒		
・農業用ハウ	ス 95	棟(冬期のみ)			

Figure 26 Matsukawa condensed water supply destination after geothermal power plant power generation

End.

## 7 Editor words

High efficiency energy conversion in International Linear Collider (ILC) is an inevitable issue among advanced accelerator project. ILC should be the model for use of high-efficiency equipment, and the use of sustainable and renewable energy sources. The Technology Group of the Association of Adavanced Accelerator Science and Technology Promotion began a study of this issue. This report is a summary about the technology being studied which has been proposed at green ILC Working Group in February 2014 to March 2015. Technical study is intended to make continued even after April 2015, but the present report is the first stage of the study results, which will be a help document at the time of ILC detailed design stage in the near future. We would like to keep both the Japanese and English version of this report in the ILC-related web-page.

Individual presentations at the working group can be found at;

https://aaa-sentan.org

See the member pages of the inside.

Editor May 27, 2015