STUDY ON A SUSTAINABLE ENERGY MANAGEMENT SYSTEM FOR THE ILC

Masakazu Yoshioka #, A, B, C), Tohru Kano B), Shinya Narita C), Hisashi Odaira D), Sadayoshi Hirai E), Yasuo Kawabata F), Junji Sawai G)
A) Tohoku University
B) Iwate Prefectural University
C) Iwate University
D) Iwate Prefectural Office
E) NTT FACILITIES, INC., Solution Business Department, Tohoku Branch,
F) TOBISHIMA CORPORATION, Civil Engineering Division
G) Sumitomo Mitsu Construction Co,.Ltd. Civil Engineering Division

Abstract

A large accelerator facility is also a large power load facility. In that sense, Japan's largest facility was TRISTAN and KEKB of KEK with a maximum contracted power and annual power consumption of 96 MW and 500 million kWh, respectively. Electricity was received from the commercial grid and the end thermal energy was released into the air with a cooling tower. However, in recent years, sustainable energy management of large-scale accelerator facilities has become a prerequisite for their acceptance by society worldwide. Since the ILC would use more power than TRISTAN, its facility design should be based on that idea. In this paper, we discuss not only electric power used in the ILC but also the general and comprehensive management of electric power and thermal energy based on the characteristics of the entire region where the facilities are to be located. Energy sources including electricity will be comprehensively considered, such as commercial grids, co-generation, seasonal solar heat utilization, heat utilization of unused biomass, geothermal, hydropower, and wind power. Finally, we propose a new energy management system that would be set in motion by ILC.

1. Introduction

In April 2020, ICFA announced that it will set up an international team for realizing a pre-laboratory for the ILC, which will be hosted by KEK, and at the beginning of August it was announced that the International Development Team (IDT) had been organized. In June 2020, it was also announced in the European particle physics strategy [1] that *"the timely realization of the electron-positron International Linear Collider (ILC) in Japan would be compatible with this strategy and, in that case, the European particle physics community would wish to collaborate"*. Japan-US talks on academic-government-industry levels have been ongoing since 2013, but at the LCWS2019 in Sendai in November 2019, State Department officials announced that they would commit to the ILC together with the Department of Energy [2].

In summary, as a strategy for energy frontier physics around the world, CERN will develop and prepare the Future Circular proton-proton Collider FCC at the center of mass energy of 100 TeV while operating the High Luminosity LHC until around 2038, and operate it from the mid-2050s. Regarding the ILC, with the IDT at the center, we aim to establish the ILC pre-laboratory by the end of next year and to start operations at the ILC after the mid-2030s.

The European strategy includes items relevant to the present paper. It requires that future accelerator facilities be based on the concept of energy sustainability. The passage is quoted below: *"The environmental impact of particle physics activities should continue to be carefully studied and minimized. A detailed plan for the minimization of environmental impact and for the saving and re-use of energy should be part of the approval process for any major project"*. Needless to say, the ILC should also be based on this idea. Since around 2014, we have called this concept "the Green ILC" and have conducted various R&Ds regarding the construction of sustainable research facilities based on the characteristics of the ILC candidate site. The purpose of this paper is to report the overall picture of those activities.

2. Overview of Green ILC

Looking at the accelerator as a power load facility, TRISTAN had the highest peak power at an accelerator facility in Japan, with a maximum contract power of 96 MW. The maximum value of annual electric power consumption was KEKB with 500 million kW hours. The ILC is expected to have a peak power of 120 MW and an annual usage of about 700 million kW hours depending on its annual operational time, which is more than our previous experiences. In summary from the viewpoint of energy flow, we would first accept electricity from commercial grids and private cogeneration, which would also serve as a backup power source. The input power would eventually become thermal energy in the accelerator, detector and utility equipment. Cooling equipment would heat up the water in the cooling water system, and that hot water would be dissipated from cooling towers installed in the ground. Next, we will summarize each step of the Green ILC concept.

The 1st step is to optimize the beam performance (luminosity) per power consumption in the parameter

masakazu.yoshioka@kek.jp

settings of all ILC devices. This has already been incorporated by the efforts of the accelerator designers such as utilization of superconducting equipment, nano-beam collision scheme, and polarized beam collision.

In the 2nd step, the energy efficiency of all accelerator equipment would be improved, and ongoing development research, for instance, on the Q value improvement of the superconducting cavities and the efficiency improvement of the klystron and modulator power supply would be continued.

The 3rd step would be to select a sustainable source of electricity as the ILC's power source. The Tohoku region is advantageous in this respect. ILC's peak electricity is 0.5 to 1% of the electricity generated in all of the Tohoku region, while sustainable electricity such as hydro, geothermal, wind, solar, and biomass exceeds 20% of the electricity produced in the Tohoku region. Therefore, it would be easy to limit electricity contracts to sustainable sources. But this is not our endeavor. We must consider more active sustainable energy management methods.

The 4th step would rely on the efforts of ourselves and the region where the ILC would be located. First, we will position "The Global Village Vision" formulated by the Global Village Planning Committee [3] as our higher-level philosophy. In that vision, the following four items are listed as problems to be aware of: (1) a fragmented-international society, (2) the appearance of a huge capital market due to economic globalization and changes in the world's social and economic systems, (3) technological development and its shadow such as 5G, IoT and AI, (4) global warming issues.

The vision also emphasizes the following items based on Japan's view of nature, society, history and culture, and abundant natural environment: (1) Satoyama culture (culture of the "hilly heartland" - ie, villages in the vicinity of mountains) since the Jomon period (prehistoric culture up to about 1000 BCE), (2) World Heritage Site Hiraizumi's idea of the pure land, (3) a history of forming a recycling-oriented society since the Edo period (1603~1868), (4) the abundance of various forests, the sea, and food culture, (5) a history of incorporating different cultures and different civilizations. On that basis, we will gather wisdom and tackle the global issues mentioned above. Below, based on this higher-level philosophy, individual efforts based on the characteristics of the Tohoku region are described.

3. The "Green ILC" concept rooted in the Tohoku region

First, we have established a collaborative system of industry, government, and academia to base our activities. "Academia" refers to Iwate University and Iwate Prefectural University, "Government" means the Iwate Prefectural Government and the Iwate Industry Promotion Center, and "Industry" means the working group companies under the Advanced Accelerator Association Promoting Science and Technology project promotion subcommittee (hereafter referred to as AAA) [4] as well as local companies, chambers of commerce, etc.

The Tohoku ILC Project Development Center (hereinafter referred to as "Center") was established in response to the establishment of the IDT in KEK mentioned above. When the Center was established, there were a total of 22 organizations at the moment; Tohoku University, Iwate University, Iwate Prefectural University, and Iwate Prefecture, Miyagi Prefecture, and municipal governments in both prefectures. Specific activities will be carried out by establishing "committees", but regarding the Green ILC, we would like to form "committees" with the above-mentioned groups that have already accumulated activity results as members.

It should be mentioned that electricity is, of course, important for considering sustainability, but we should also consider the use of heat from hot and cold water. The specific activities are summarized below.

3.1 Exhaust heat recovery from the ILC and the creation of businesses derived from it

The equipment of the ILC device is cooled with cooling water. The temperature of the hot water depends on the equipment design, but generally it is low at around 60 °C, and it is normally dissipated into the air at the cooling tower. Research on such low-energy, low-grade heat energy recovery technology is being conducted at Iwate University, National Institute of Advanced Industrial Science and Technology (AIST), Takasago Thermal Engineering Inc., and other industry-academia joint research. Details will be reported at the previous and the present conferences [5-8]. This technology is also useful for recovering exhaust heat from factories, hot springs, refuse incinerators, etc. that are mostly discarded in today's society, without needing to wait for its application to the ILC.

3.2 Connecting the ILC with the local forestry industry

The Tohoku region and the area where the ILC is located have high percentages of their area covered with forests, with an active forestry industry. Therefore, linking the ILC to the forestry industry is important for regional development. At the same time, it will also incorporate the ILC as part of a sustainable energy cycle within the region.

The 1st step is to build wooden structures to house the ILC-related facilities such as laboratories and offices, as well as housing for researchers, engineers and their families. This is a policy in line with the promotion of wooden construction of housing and large public facilities as part of the national basic policy. There are no particular technical issues regarding the construction of wooden houses. Issues related to town development and planning will be described later. On the other hand, research and development is required to make large facilities such as ILC-related laboratories with wooden structures. About this issue, we have already published a paper at the previous PASJ meeting [9]. Details are described in the literature, but we used a model where red pine produced in northern Iwate Prefecture is processed into laminated wood in the central Iwate Prefecture, and a local construction company takes charge of the construction. As a result, it was found that wooden structures were superior to steel structures in terms of direct cost, primary and secondary economical ripple effects and the increase of employment.

The next step is to promote using scrap wood chips for heating in ILC-related facilities. In the Tohoku region, there are many examples where sawmill wood is used for papermaking and heat production. Wood chips and bark will be generated more frequently if we make ILC-related facilities with wooden structures, and those scraps can be utilized in heat production.

Finally, it was proposed we use aerial laser surveying technology in order to create forest industry policy over a wide area. Originally, this technology was developed with joint research between Asia Air Survey Co., Ltd. and Iwate University with the aim of confirming details on the condition of the ground surface with high accuracy in order to study ground facilities for the ILC. By removing tree information from the survey data, the bare surface conditions can be obtained. The accuracy is about 20 cm, depending on the number of data points. Conversely, the removed digital data contains a huge amount of information related to trees, and tree species and tree height can be identified. This will be applied to the forest industry. For details, please refer to the reference [10].

3.3 Utilization of solar heat

Although solar power generation comes to mind as a use of solar energy, it should be noted that the efficiency of converting energy into electric power is 20% or less. As mentioned above, in the Tohoku region, more than 20% of total power sources are sustainable power sources including solar light, and it can be considered that the waste heat recovery explained in the previous section will be utilized as local energy in local industries. Therefore, we consider the use of heat from solar energy as a further heat source. We investigated the case of Denmark, which is an advanced region using solar heat [11]. There, solar panels with a thermal output of 27 MW (installation area: 3.7 hectares) and an underground pit-type heat storage tank with a capacity of 62,000 cubic meters cover 40% of the heat source of 3,700 communities. With this method, it is possible to store thermal energy over the seasons.

When this system is introduced to Japan, there will be items that require new technological development: the sloshing problem on the water surface due to earthquakes in a large-capacity underground pit-type heat storage tank and the deterioration problem of the heat insulation effect of soil due to aquifers. If these problems are solved, it will be one of the most effective heat sources in mountainous areas such as the ILC candidate site.

3.4 The Green ILC concept and community development and planning - building an energy recycling society based on the Global Village Vision

Up to this point, an overview has been given for each item of technological development. In this section, I will explain how to put them all together and use them in the town planning concept set in motion by the ILC.

The total number of researchers and engineers working at ILC research facilities will gradually increase through the phases of preparation, construction, and operation. Taking into account the example of CERN, an international research institute, I think that ILC could have a total scale of 5,000 people. When factoring in companies engaged in operation and maintenance work, the creation of new industries through technology transfer, and the increase in joint researchers, the related population will eventually reach the tens of thousands.

On the other hand, the population in the area where the ILC is located is currently undergoing a sharp natural decline. For example, in the earliest case, the ILC is expected to start operating by 2035, and by that time the population will have decreased by 16%. Compared to the amount of population decline, the increase in ILC-related population would only have a small impact on that number. However, we propose that ILC should be used to create new towns for this rapidly changing society.

We will consider arranging hundreds of units in a distributed manner as a basic concept for town development. The reasons are summarized below.

(1) Looking at the communities where research and study cities and universities in Western countries are located, it is rare that related people live in a concentrated manner. Rather, they often blend in with the area and live in a dispersed manner.

(2) Population increase related to ILC would not occur at once but gradually.

(3) The local natural environment is generally good, and the vast mountainous areas and plains are spread out. In addition, depending on the area, there are seas, mountains, rivers, snow, hot springs, swamps, etc., and people will be able to live in places that most suit them.

(4) Currently, transportation infrastructure such as expressways and Shinkansen trains is already in place, and will continue to be improved. Therefore, for example, the range of travel within one hour is wide.

(5) In addition, local community development should be adapted in line with the declining birthrate and aging of the population so that new residents can be mixed with local residents.

(6) The hundreds of community houses based on the Green ILC concept will be based on highly airtight and insulated whole wooden structures that coexist with trees and nature. There, construction work will be kept to a minimum by taking advantage of the local topography and natural environment. We will establish a core green space in the community, and develop smart agriculture that makes use of the IoT in the surrounding area. Design

codes will be set for residential buildings, materials and colors will be unified, and building sizes will be limited.

(7) When creating a community, we will not implement a style of selling and withdrawing. We will create a management system, thoroughly implement area management, and make it a management structure that is able to grow. We will prepare various types of houses such as detached houses, terraced houses, multi-family houses so that they can respond to changes in the lifestyle and income of residents. There, we will create a 5th generation town that incorporates cutting-edge technologies such as IoT and AI so that we can respond to future technological changes.

(8) Establish an energy center in the community. Electricity will be received collectively, and cold and hot water can be supplied and distributed to each house. As an energy source, in addition to electric power and fossil fuel, hot spring heat, geothermal heat, unused biomass, solar heat utilization and unused exhaust heat are used according to the characteristics of the region.

(9) For the purpose of moving to established towns and markets and commuting to ILC-related facilities, we will also consider introducing fully automatic electric vehicles and eVTOL, which is likely to be put into practical use in the near future.

4. Summary

The basis of the Green ILC concept is to make the ILC with a regional energy circulation system that is closely linked to the characteristics of the region surrounding it. In other words, it should be a model of regional planning in Japan, set in motion by the ILC, while making use of various technologies based on the Global Village Vision as a higher philosophy. We believe that this concept is a necessary condition for social acceptance when locating large accelerator facilities, not limited to ILC.

Acknowledgment

This paper is based on the work of a working group under the Project Promotion Subcommittee of the AAA. It also refers to the contents of regional study groups related to ILC that are established in various areas of Iwate Prefecture. Finally, we also referred to the joint research results of Iwate University and private companies. We extend our deepest thanks to those groups.

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