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History of Power Systems Development in Japan

—"Repeat Model" for the History of Engineering —

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Abstract

There are similarities and differences between the study of history in general and that of the history of engineering in particular. Since the study of engineering seeks for the practical use, the productivity of the study will be essentially estimated, if it will meet with the need of human life and society, just like "Innovation," for instance, will be. This paper tries to find some keys for the successful innovation through the history of engineering. It suggests what can be called as "The Repeat Model." Taking the case of power systems engineering development in Japan, the author finds in the Model the repetition of such sub-stages as "introduction," "application," "innovation" and "turbulence" in each stage of history. Since power system planning is one of essential know-how in power systems engineering, it will be critically important to improve the know-how through the use of "The Repeat Model" for the welfare of society in the future under such condition as human needs, deregulation and social contradiction. The author also discusses that the study of history is important and effective to establish public literacy and ethics on engineering and to develop the engineering in the right direction for the welfare of society.

1. Historical Study of Engineering

Most engineers tend to think that piling up of historical facts could be meaningful historical study. These facts they deal with are important as they are results of experiment, natural phenomena found by observation, through theorems and formula applied to analyze data and/or products used in daily life.

On the other hand historical facts dealt with in historical studies are generally the record of history materialized by observers on site or historian who study them. Since everyone can doubt the "truth" of the record, a paper on the study of history is supposed to show evidence of its historical facts in the form of materials to be referred to.

Just like a paper of engineering study, a paper on engineering history study must be written on the basis of sound technical and historical facts and by way of rational and reasonable rhetoric. Since engineering study and history study are different in regard to facts to be based on and to results to be estimated, difference between the two will be shown as the **Table 1** below in terms of subjects discussed in the paper as an example.

In accordance with the discussion above, the paper on historical study of engineering shall include the following; [1]

(i) Historical material: A paper shall carry the lists of reference as the evidence of historical facts, so that the reviewer will be able to confirm the credibility of material to be referred to for the confirmation of historical facts.

(ii) Chronological table : It is not necessarily essential for a paper to carry the chronological table but, in some cases, the table will be effective for the clarity of description, though it is not the primary historical material.

(iii) Historical Point of View : It is the most critical for a paper to identify the purpose of its study, showing its historical point of view, as the view is the basis of its originality and identity.

(iv) Historical Analysis : In case a paper only shows historical facts, it will not be qualified as a historical study, though it will be useful as a review of historical facts. In order to analyze historical

Scopes \ Study	Engineering	History	Remarks
Facts to be based on	Theorem, Formula Experimental data	Historical material Chronological table	Evidence (Reference)
Results to be estimated	Discovery, Invention Products, New theory	Historical point of view Historical analysis New historical material	Usefulness

Table 1 Study of Engineering and of History

facts it is essential to show not only the author's historical point of view but also his way of analyzing them. In case the way of historical analysis, a **"Model"** for instance, is applicable to the other historical facts, it may become useful to study history as a whole.

(v) Previous Works : In order to show its originality and identity a paper should identify and make analyses on previous works. There will be no problem to analyze historical facts on the similar historical point of view as the works done previously, but a paper is supposed to show its originality and identity in other ways as well.

(vi) Usefulness: Since the study of engineering draws on practical experience, the productivity of the study may be measured in terms of the need of human life and society just like "Innovation," for instance, will be. Though historians do not necessarily care if their study contribute to the society but seek for the truth, engineers are supposed to make their work productive for the better human life and society, even in case of historical study of engineering.

2. Power Systems Development in Japan

2.1 Industrial Electrification (1890s to 1940s)

The development of power systems in Japan started in 1887, only five years later than that in the city of New York in 1882, when the Tokyo Light Co. began DC power supply in the city of Tokyo. In 1892 full power from the Keage hydropower station was supplied to the city of Kyoto, being developed with civil work of water supply from the lake Biwa.[2] Industrial systems and engineering were introduced from the West in parallel with the other social systems in the course of Japan's modernization. The disputes between DC and AC systems happened, differently from the case in the US, not in the market but corporate internal competition, so that the disputes did not make any serious social issues.[3] Innovation in Japan led to the increase in distance and voltage of transmission lines, resulting in the improvement in power grid supported mainly by hardware development. In the year 1935 power supply to the metropolitan Tokyo area and industrial Keihin area was made by 154 kV transmission lines running more than 300 km from hydro power plants in Northern and Western mountain area from Tokyo, as shown in **Fig 1**.[4] One of examples showing the remarkable progress of power systems engineering in Japan is the fact that the test of "wired wireless" was successful for the first time in the world in 1918 to transmit signals on power lines of 66 kV running from hydro power station on Kinugawa River to Tokyo area.[5]

Serious competition in power industry in 1920's made power companies merge into Major 5, sharing a half of national capacity more than 1000 MW. In 1938 they were kept under the public control for the military purpose of industrial electrification. Though the test of AC network analyzer was successful in the US, the technology was not successful to be transferred into Japan due to military conflict between the two. Thus the World War II brought serious turbulence to the development of power systems in Japan, while the turbulence came to be a bed of the innovation for the following stage of historical development.

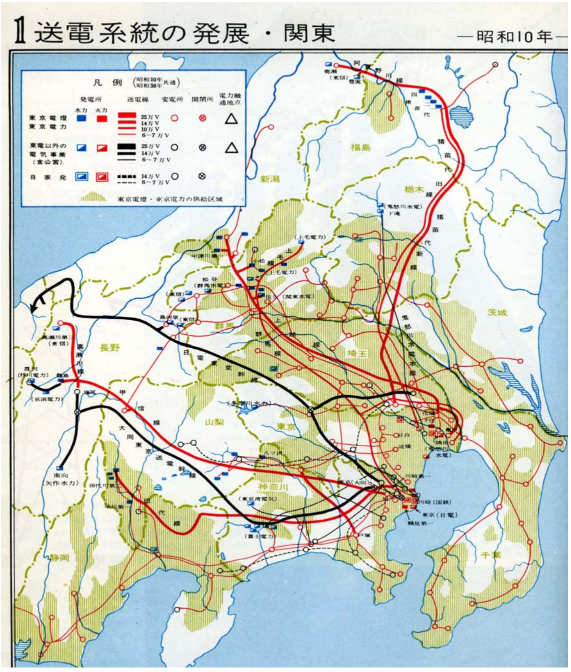


Fig. 1 Transmission Lines to the metropolitan Tokyo area in 1935

2.2 Household Electrification (1950s to 1980s)

The recovery of Japanese economy from the damage was remarkable in the 1950's thanks to intense investment in power and coal industry, which were two major energy industries in Japan after the WW-II. Yet the high rate of economical growth of industry in the 1960's caused serious harm to human health in Japan especially in the form of environmental pollution. In addition, the "Oil Crisis," due to the oil embargo by OPEC in 1973 and 1979, made Japanese industry quite energy conservative and slowed the Japanese economic growth. The concern for the Japanese people shifted from industrial development to human welfare. As a result, the household

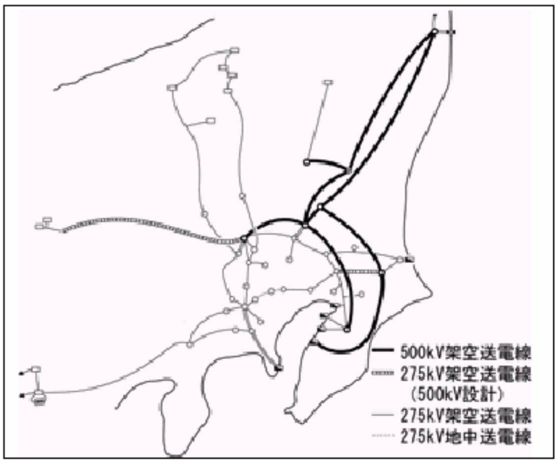


Fig. 2 Circular Network surrounding the metropolitan Tokyo area in 1975

electrification gained its momentum.[6]

Power systems in Japan introduced newly developed computer technology in order to meet with the growing demand and social needs for stable and reliable supply of power on the basis of the new networking of power systems and restructuring of power industry to the democratic and private scheme. As shown in **Fig. 2**,[7] circular networking and systems interconnection supported the stable and reliable supply of power to heavy demand areas like city of Tokyo, Osaka and Nagoya, etc. Also the information theories to back up the computer software were applied to the power system control engineering. These theories were applied to the power systems engineering for its innovative development. One of its evidences is found in the process of technology development for power systems simulation[8] shown in **Fig 3**. The hardware of large scaled computers fixed in Central Systems Control Offices for each demand area in Japan was made full use to control large scale power systems. In order to operate the hardware the software of information theories and operation systems for computer dealt with large amount of data in power systems. In this manner the circular networking and interconnected power systems were controlled by central control system to maintain the stable and reliable power supply for not only industrial demand but still growing household demand. The key word for power systems engineering in the 1960's was "Toughness," that is, to establish the system as tough as possible for any kind of change in circumstances. Due to the fact that the growth of Japanese economy came to be stabilized, particularly after "Oil Crisis" in the 1970's, hardware development, just like power systems equipments and facilities, were no more remarkably progressing. The Japanese power systems in the 1980's and later were heavily dependent on software development in terms of their engineering to make it as flexible as possible against the change of circumstances.[9]

2.3 Intelligent Electrification (1990s to 2010s)

It was not only the "Oil Crisis" but also the competitive global market that had changed economic and social circumstances in Japan, which naturally had serious effect on power industry and systems to cause the turbulence. At the turn of Century the industry was now supposed to be much more customer oriented than ever, though it used to be rather public oriented as one of basic industries in economy and society of the nation. Customers became more and more efficiency sensitive not only for economic reasons but also for environmental protection.

In order to face with the new stage of economic and social circumstances the Japanese power systems introduced electronic technologies including digital control, autonomous distributed control for power systems and thyristers for HVDC transmission, which controlled power systems much

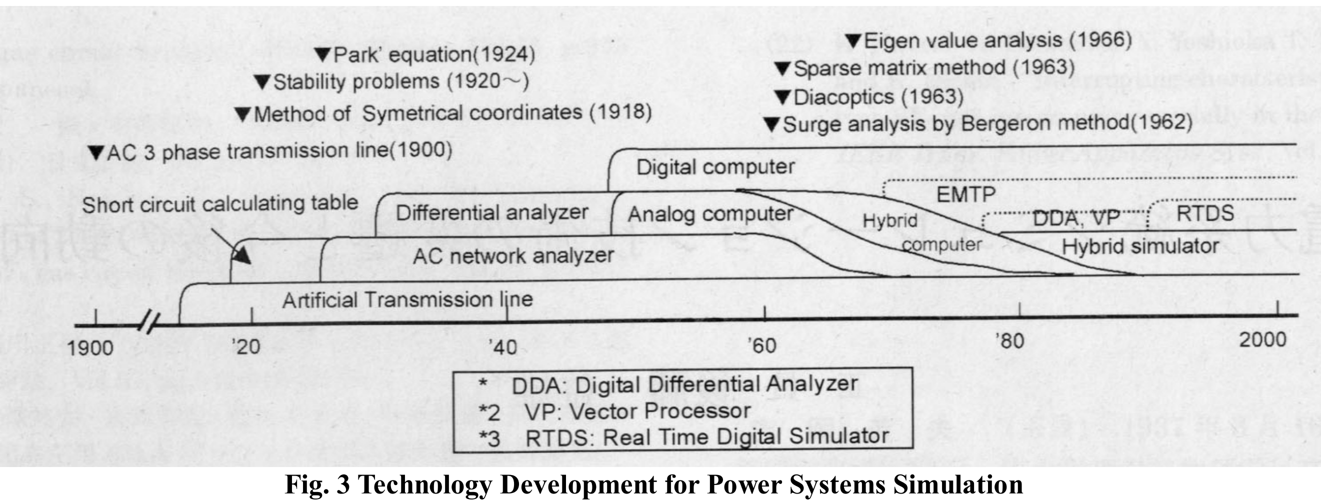


Fig. 3 Technology Development for Power Systems Simulation

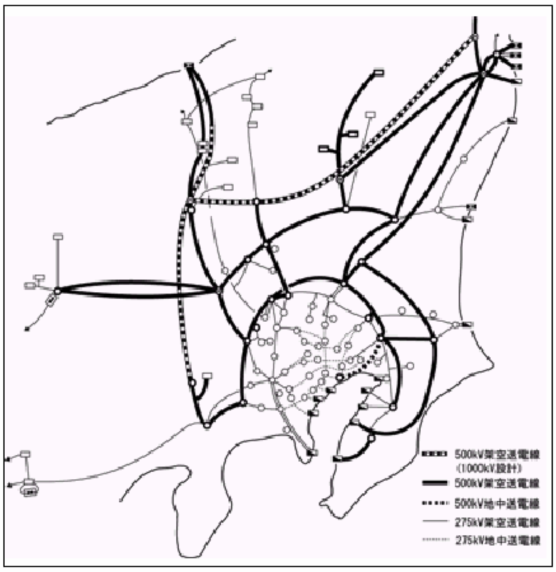


Fig. 4 Circular Network surrounding the metropolitan Tokyo area in 2005

more intelligently against the background of information age. As the demand side of power systems came to be more energy efficienct and price/cost sensitive, real time pricing in the rate system and demand side management system were not only accepted by customers but also made feasible due to innovative and intelligent development in power systems control engineering. With the back up of large scaled and high voltage network surrounding heavy demand area, as shown in **Fig. 4**, [10] small scaled distributed power supply systems like co-generation, micro gas turbine has now been combined in power supply system, as well as the renewable power of photo-voltaic and wind power to help with environmental protection.

The combination of small scaled distributed power supply systems could cause any turbulence from system control point of view, but the threat of much more serious turbulence now covers the power systems and industry in Japan. In parallel with the development of information age the deregulation in power industry is now developing as one of political and economical agenda in Japan to undermine the sound base of power industry. It is true that the competitive market provide industry with active mind, yet, with rather short sighted decision making, which is not always appropriate for power systems to be maintained and operated for long time more than 10 – 20 years.

Actual turbulence in both power systems and industry was seen in the West coast of US, where serious black-out and extra-ordinary price hike of electricity happened due to mismanagement in regulatory body and power companies in the process of deregulation. There are many kinds of criticism against what happened there [11] and one discussion[12] cites to remind the "roots" and spirit of engineering that established "the world's best power system" as the National Academy of Engineering called, "the greatest technical achievement of the 20th century."

The similar turbulence could happen also in Japan but, fortunately enough, Japan has learnt lessons from what happened in the US, so that they are trying to make such turbulence as small as possible and to make power systems and industry controlled in an intelligent manner. Taking the turbulence in the US and current circumstances in Japan into account, it seems for Japanese power systems and industry to wait more than ten years from now until a new stage of history will come in the 2010s when they will get rid of the current turbulence.

2.4 Welfare Electrification (2020s ～)

In order to get rid of the current turbulence Japanese power systems and industry are supposed to introduce new technologies and economic systems for the development of the next historical stage. The choice must be made to meet with needs of the new society for security and welfare of people in Japan. The introduced technology is to create the innovation in the new society so that it will maintain high standard of living through the efficient use of energy to conserve natural environment.

From technological point of view super conductive power systems and hydrogen energy systems, for instance, will be some of technologies to be introduced for the development of next stage of power systems that will be referred to as "Welfare Electrification." Since power systems in one country must take global society into account now, global **Technology Interaction** must be one of key factors to be taken care of. From economic point of view competitive market oriented systems may not necessarily be the most appropriate one for the welfare of people, as competition sometimes forces people to forget the roots and spirit of engineering that established "the world's best power system." For the stable development of power systems composed of such equipments and facilities as developed, maintained and operated for long time more than 10 – 20 years, the effectiveness of long range planned economy shall be reviewed and implemented in the next stage of power systems. [13]

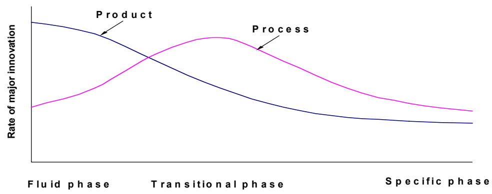
Since it is a matter of planning how to develop the next stage of power systems in Japan, power systems engineers must study the history of power systems engineering to find the most appropriate direction and source of technology, making full use of their ability of power systems planning cultivated so fur in the development, maintenance and operation of power systems. As the plan must be for the people and be accepted by the people, it is quite important to restructure the public engineering relations, which requires a better public literacy in power systems engineering.

3. Developing a Model

One of effective ways to study innovation is to develop a model in regard to the history of technology, as a model may make it easy to understand the development of innovations and of technology. One example of such models to study innovation is the Abernathy -Utterback model, which has been popularly applied to the study of innovation and industrial evolution.[14] (**Fig. 5**)

Fig. 5. Life cycle of an industry or product class

Abernathy (1978: 68-85), Utterback(1994: 79-102).



The author proposes what he calls “The Repeat Model” (**Table 2**) with intention as to develop a practical and productive method for studying the history of engineering, and hopes to raise the interest of students and young scholars in the subject. The Repeat Model is a modification of the Stage Model composed by Dr. Yakushiji, Taizo, at Keio University for the study of technological development in automobile industry in Japan.[15]

Table 2 The Repeat Model

(Applied to the case of Power Systems Development in Japan)

Stage (year)	Sub-Stage	Stage Model* (Node) / its Expansion	Power Systems in Japan: Technological Factor	Power Systems in Japan: Social Factor
			Industrial Electrification	
First	Introduction	(1) Antecedent Factor	AC and DC	Power Industry in the West
(1890)	Application	(2) Imitation and Primary Emulation	Simultaneous Dispute on AC/DC in Japan and America; Increase in Distance and Voltage of Lines	Compete in Power Market
(1920)	Innovation	(3) Primary Industrial Order	Improvement in Power Grid (Hardware Development)	5 Major Power Companies; Public Control of Market
(1940)	Turbulence	/ Maintaining the Dominance		National Power Operation
			Household Electrification	
Second	Introduction	(4) Technology Transfer and Planting		Consumption Control
(1950)	Application	(5) Articulation of Restrictive Condition	Systems Interconnection	Restructuring in Industry
(1960)		(6) Dominance and Renewal	Computer/Reliability Control	
		(7) Major Actor	Toughness	Economical Operation
	Innovation	(8) Secondary Emulation and Industrial Order	Central Systems Control (Software Development)	Wide Area Coordination
(1970)	Turbulence	(9) Maintaining the Dominance		
			Intelligent Electrification	
Third (1990)	Introduction	(10) Trickle Down and Boomerang Effect	Digital Control System; Autonomous Distributed Control	Information Age and Deregulation
	Application	(11) Risk Management or Withering	HVDC; Real Time Pricing; Demand Side Management	Environment Protection Policy; Non-Professionalism / T A**
(2000)	Innovation	/ Third Emulation and Industrial Order	Flexibility (Hybrid Development)	Independent Power Supplier
	Turbulence	/ Maintaining the Dominance		Global Market Fund
			Welfare Electrification	
Forth	Introduction	/ Coping with Risks and New Industrial Development	Super Conductive Power Systems; Hydrogen Energy Systems	Restructuring the Public Relations
	Application	/ Global Contribution		Review the Effectiveness of Planned Economy
	Innovation -----	(to be continued)	Global Technology Interaction to be discussed from cultural point of view	
Nth	Introduction			
	Application			
	Innovation			
	Turbulence			

*: Stage Model is composed of 11 nodes.
**: Technology Assessment

Table 3. History of Power Systems Development in Japan

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Year	Power Systems Engineering in Japan	Year	**Power Industry in Japan** and Global Circumstances	Relative Engineering
	Industrial Electrification	1867	Self exciting generator by Siemens et al.	generator
		1871	IEE established in London	
				DC
1878	On **25th March** an arc light was lit in the hall of Eng. College	1878	Carbon filament light bulb by Swan	light bulb
	(Japanese memorial day of "Electricity")	1882	Central DC power station in NYC	power station
1883	Arc lights lit by the first generator of domestic production		Transformer by Gibbs	transformer
		1884	AIEE established in NYC	
		1886	**TOKYO Light Co. established**	
1887	DC power supply in Tokyo (210V 25kW)			
1888	IEEJ established in Tokyo	1888	AC power supply in London	AC
1889	AC (125Hz) power supply in Osaka (1155V 30kW)			
1891	Keage HPS partially in commission (2 x 550V DC unit)	1891	Expo power by AC transmission in Frankfurt (15kV 240kW 17.5km)	transmission line
1892	Keage HPS addition in commission (1 x 1000V AC unit)			hydro power
1896	Asakusa Thermal PS (50Hz AC)			thermal power
		1897	**AC (60Hz) power supply in Osaka**	
1899	11kV 26km AC transmission in Hiroshima			60Hz
1907	55kV 75km AC transmission from Komahashi to Tokyo			50Hz
1915	115kV 228km AC transmission from Inawashiro to Tokyo			
1918	Successful test of telecommunication on power line			
	(for the first time in the world)	1920s	**Power companies were merging into Major 5**	
1921	Dr. Shibusawa suggested the union of transmission voltage	1921	**National total generation capacity reached at 1000MW**	
1923	154kV 301km AC transmission from Azusagawa to Tokyo			154kV
1927	154kV 351km AC transmission from Kurobegawa to Tokyo			
		1929	AC network analyzer for test in US	AC network analyzer
			Major 5 shared a half of national capacity	
		1932	**Major 5 contracted in cartel**	
1935	26.2MW steam turbine generator produced in Japan			
	(marked the world record)	1938	**Power industry under the public control**	
1945	100kV AC overhead line crossed over Kanmon straight	1945	**WW-II settled down**	

Year	Power Systems Engineering in Japan	Year	**Power Industry in Japan** and Global Circumstances	Relative Engineering
	Household Electrification			
1950	AC network analyzer fixed at the National Electric Labo.	1950	**Power industry under the Public Utilities Committee**	AVR
1952	Numazawanuma pumped hydro PS	1952	**Electric Power Development Promotion Low enacted**	Pumped Hydro
	275kV AC transmission from Kurobegawa to Osaka			LRT
		1955	**3 Nuclear related laws enacted**	
		1956	300MW NPS in commission in UK	Nuclear Power
		1958	**Wide Area Coordination organized**	
1959	Ohmorigawa pumped hydro PS	1960	**MHD generation was successful in US**	MHD
	AFC in commission in Kyushu	1961	**Thermal overcame hydro generation by energy**	AFC (LFC)
1963	12.5MW nuclear power generation			EDC
	Sparse Matrix Method, Diacoptics	1964	**Power Industry Law enacted** IBM/360 on line	System Supervision
1965	300MW Sakuma Frequency Converter Station			Host Computer
	(Direct interconnection of 50/60 Hz systems)	1965	**Damage on Miboro Trunk Lines** **Black-out in Osaka**	HVDC
1966	125MW GCR generation at Tokai		Black-out in NYC	AQC
	Static **S**ystem **C**ontroller in Chubu	1966	Eigen Value Analysis	SSC
1970	331MW BWR, 350MW LNG generation	1970	EMTP developed	Plant Control Center
	340MW PWR generation (Power for Expo)	1971	Intel Micro Computer on sale	CDT
				EMTP
1973	Numappara pumped hydro PS (675MW 478m)	1973	Oil embargo by OPEC	PSS
	500kV AC transmission from Boso to Tokyo			Digital Communication
		1977	Black-out in NYC	
1979	150MW 125kV DC cable transmission	1979	Three Mile Island NPS in accident	
	(Hokkaido-Honshu HVDC Link)			
1980	500kV AC transmission from Kyushu to Osaka	1980	Iran-Iraq Conflict	
1981	Shintakasegawa pumped hydro PS (1280MW 229m)			EWS
		1985	**NTT established (public corporation privatized)**	
		1986	Chelnobuil NPS in accident	
1987	Tenzan pumped hydro PS (600MW 520m)	1987	**Black-out in Tokyo**	
		1989	Ten-an-mon riot	
	Intelligent Electrification			
		1990	Reunion of Germany	RTDS
1992	Hokkaido-Honshu HVDC Link escalated to 600MW (250kV)			
1994	500kV AC cable transmission from Honshu to Shikoku	1994	**Power Industry Law modified for deregulation**	
		1996	**First bidding for Independent Power Producer**	
1999	Sea Water pumped hydro PS in Okinawa (30MW 136m)			
		2001	9.11 Terrorism	
		2003	Blackout in NE America	
		2005	**Japan Power Exchange established**	

The Repeat Model is composed of several repeated stages each including four sub-stages of Introduction (Invention or Transfer), Application, Innovation and Turbulence so that the model could suggest the right direction for engineering to develop in the future. The composition of "The Repeat Model" is made in such a manner as to pick up some key words or key phenomena from chronological table in terms of the history of power systems development in Japan. (**Table 3**) It is, of course, matter for discussion whether or not the model is appropriately applied to the historical development of power systems in Japan. And, yet, the model could be effective to make power systems planning as reasonable as possible and to develop the plan on the base of historical facts.

The model shall be applied to every field of technology and engineering so that we will be able to find not only the key to the successful innovation but also the right direction for technology and engineering to be developed. Since the young engineers are accustomed to handle models, model study on technology and engineering history will be one of the easy and appropriate introduction for the young to the study of history, though there are some difference between technological model and history model.

4. Future Perspective

It will be a matter of discussion whether technology is continuous or not, as innovation means a critical change in systems of technology in society. Yet, it will be easily found that the innovative technology has been established on the base of relevant technology already developed so fur, so that there is some kind of continuity between innovative and relevant technology. The relation between the two will be clearly shown in "Repeat Model" that the emulation of technology creates the innovation, which establishes the industrial order repeatedly in each stage of technological development. The Model also shows that the successful emulation will be made on the sound basis of relevant technology for successful innovation.[16]

The right direction for technology and engineering to develop will be referred to as that innovative technology and engineering are supposed to enhance the welfare and prosperity of human beings on the globe. The rightness of direction shall be judged by the heritage and virtue of culture and civilization in which innovative technology and engineering play their roles. In order to implement what is mentioned above, practical measures including industrial policy, corporate planning and academic objective shall be productively developed so that every engineer on the globe will make his productive global contribution.

The right direction for technology and engineering to develop will be also matter of public decision by way of democratic discussion. For the proper decision making **public education**, particularly in terms of science and technology, will be one of the most important factors. As was discussed in ICEE 2006[17], OECD Secretary General, D. J. Johnston gave his remark in its Home Page,[18] "Society's most important investment is in the education of its people. We suffer in the absence of good education: we prosper in its presence." This indicates the importance and effectiveness of public education especially for science and engineering **literacy** to face with the challenges of the new, dynamic and diverse society in the new Century.

In order to face with the dynamic and diverse society, a firm philosophy or the moral code of action, supported by the sound code of **ethics**, is inevitable for engineers to deal with the social conflicts and to develop innovative technology for the new society. In case an engineer and his society fail to establish a sound code of ethics, he may become only a tool for politicians and/or managers in corporations seeking to pursue for their selfish benefits, as the history proves it.[19]

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He was born in Tokyo in 1940. After he graduated the University of Tokyo, he joined in EPDC (J Power) as a power systems engineer. From 1965 to 1967 he worked for the construction of HVDC facilities of the Sakuma Frequency Converter Station with engineers of ASEA. After working for the development of HTGR with GGA engineer, he was assigned in the Marketing, Planning and R&D Division from the '70s to '90s. From 1980 to '84 he was stationed in Washington, D. C. area as a member of the Joint Progarmme Management Team for SRC-II Development to represent Japanese Government. In 2000 he moved to GEI, Inc. as an Exec. Senior Engineer. He worked for the establishment of HEE/IEEJ in 1990 and supported the activities of the Maui Meetings in 1995, 2000 and 2004. He signed in "Tokyo Declaration" to establish ICEE in 1994, assuming a member of its Steering Committee and/or Organizing Committee from 1995 to 2000 and a moderator of its Special Panels on Technology Transfer in 1997, 2001 and 2002. Now he chairs IC/HTI. He is a member of IEEJ, IEEE, CIGRE, AIEE, JASTJ, HSSJ.

References

[1] Technical Committee on the History of Electrical Engineering (HEE); "Paper on Engineering History Study" HEE-68-6 Material discussed in the 68th meeting of HEE June 2007

[2] Yanabu, S.; "History of Keage Hydroelectric Power Station" Paper presented at 2007 IEEE Conference on the History of Electric Power Aug. 2007

[3] Sakamoto, S.; "AC/DC Disputes" Arakawa, F.; "What we Learn from AC/DC Disputes" (Both in Japanese) HEE News Letter #43 pp.1-3 Aug. 2007

[4] The History of Modern Japanese Industry III "Power" (in Japanese "Denryoku") Illustration pp.76 Jan. 1964

[5] Mischa Schwartz; "The Early History of Carrier-Wave Telephony over Power Lines" Paper presented at 2007 IEEE Conference on the History of Electric Power Aug. 2007

[6] DIH/HEE; "Domestic Innovation History of Electrical Engineering in Japan" IEEJ Technical Report #603 Sep. 1996

[7] Nakamura, A; "Power Systems in TEPCO— Development History and Future Perspective" Proceedings of IEEJ Annual Meeting Jul. 2005

[8] Gotoh, Y. "Historical Trends of Electric Power System Simulation Technology" HEE-02-1 Feb. 2002

[9] Arakawa, F.; "From Toughness to Flexibility" Paper discussed at CIGRE SC-37 Jul. 1987

[10] Nakamura, A; "Power Systems in TEPCO— Development History and Future Perspective" Proceedings of IEEJ Annual Meeting Jul. 2005

[11] Hederman, W.; "The Influence of Electric Technology on Policy and of Electric Policy on Technology" Paper presented at 2007 IEEE Conference on the History of Electric Power Aug. 2007

[12] Casazza, J.; "Forgotten Roots" Opening Address at 2007 IEEE Conference on the History of Electric Power Aug. 2007

[13] Ishii, S. & Arakawa, F.; "Technology Creation" (in Japanese "Gijutsu Souzou") pp.24 Fig.1.1 Published by Asakura Shoten Jun. 1999

[14] Könich, P. C.: "Deconstructing Japan's 'crisis' of innovation" Paper presented at Innovation Engineering Forum May 2004

[15] Ishii, S. & Arakawa, F.; "Technology Creation" (in Japanese "Gijutsu Souzou") pp.22 Table.1.1 Published by Asakura Shoten Jun. 1999

[16] Arakawa, F.: "Innovation — Discussion at MIT" Innovation Engineering Vol. 3. Aug. 2003

[17] Arakawa, F.: "Education for Emerging Technology —Importance of History Education—" Proceedings of Special Session in ICEE 2006 pp. 7 Jul. 2006

[18] http://www.oecd.org/document/

[19] Arakawa, F.; "History Study for Electro Engineering Literacy —Cooperation for the Public Education—" ICEE 700 Jul. 2007