12. To Make RE a Trunk Power Source

Is it Possible to Make RE a Trunk Power Source?

To make RE trunk power source has become a today's political theme. In former chapters the author introduced methods to interconnect much RE stably using available techniques only. As a result, some limit existed in RE amount. Because power system has maintained stable depending on ability of synchronous generator, and become unstable by replacing synchronous generator to RE with poor ability. It is impossible to supply all loads by RE only using only today's available techniques. Because, "only RE supply all loads" means "islanded system of RE", and such a system cannot be maintained stable in a long time, and in addition, "anti-islanding" actively make the islanded system unstable. Once an electric engineer had pointed out that "distributed generation is parasite"(1). His opinion is correct. Therefore, some techniques must be added into them in former chapters to realize today's political issue: to make RE trunk power source.

Importance of Phase in AC Power Source

Although "to make RE trunk power source" became a political theme, progress is so slow that list up of issues is not completed. Fatal questions are the two: 1) How much RE integration limit is?, 2) What are the methods to increasing RE integration limit?

Among various phenomena limiting RE integration, the paper states as an example, limitation due to voltage stability of induction motor load. By measurement of instantaneous voltage sag, it is well known that half or more electricity is used by induction motor load that is driven by AC directly (i.e. not via inverter)(2)(3), and the result well agrees with investigation of customer's load operation(4)(5). However in Japan, power system analysis and simulation are performed without induction motor load. Such an ignorance is seen only in Japan among developed countries. Thus the paper warns that induction motor load can be a cause that limits RE integration limit.

RE Is Minus Load At first it must be pointed out that inverter power source that is the typical RE is not real power source but minus static load. Real power source such as synchronous generator has erector motive force **V** that is defined by voltage V, frequency f, and phase δ, and is written as $\mathbf{V} = V e^{j(2\pi f + \delta)}$. If voltage, frequency, or phase of power system changes, real power source goes to new equilibrium after exchanging active and reactive power between power system.

Phase of inverter power source follows that of power system. Frequency, which is time differential of phase, also follows that of power system. Voltage and phase are controlled so as to generate suitable power for voltage and frequency of power system. That is, since inverter generate active and reactive power according to voltage and frequency of power system, inverter behaves as same as a load except power flow direction. Therefore, inverter power source is a negative static load. Here, "static" means that load's active and reactive power is decided only by present voltage and frequency and is not affected by past history. Load with the opposite character is "dynamic" load. Induction motor is a typical dynamic load.

According to the situation stated above, inverter power source was modeled as negative static load in the past researches by the author(6)-(9). Even by such a simple model, behavior of inverter during and after voltage sag through experiment was well recreated(7).

Analysis Model Models are employed for solving physical phenomena. Such models should be the simplest to reproduce the phenomena. Detailed model can reflect the reality but is too complex. Therefore, only important elements are selected by idealization and abstraction in common way of natural science.

Here, 1 machine 1 load power system model shown in fig. 1 that aggregates an existing great interconnection in form of total power source vs. total load.

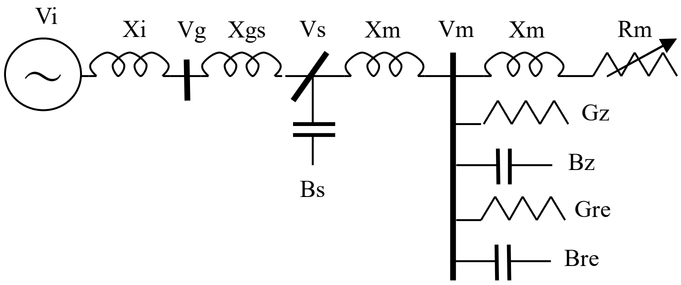

Fig. 1 Structure of 1 machine 1 load model

Synchronous machine as the infinite bus is modeled as constant voltage Vi behind transient reactance Xi. Reactance Xgs from machine terminal (voltage Vg) to system bus (voltage Vs) is the sum of line and transformer reactance for power source Xg and trunk system reactance Xs. At trunk bus trunk line capacitance and capacitor are modeled as Bs.

Xm is reactance from trunk bus to load bus (voltage Vm). Induction motor load, static load, capacitor, and RE exist at the load bus. Induction motor load is expressed as variable resistance Rm behind fixed reactance Xm. Static load is expressed as fixed conductance Gz. Capacitor is expressed as fixed susceptance Bz. RE is modeled as fixed admittance Gre + j Bre. Static load and RE are not necessarily constant admittance in general, but are assumed so for simplicity. The assumption works for voltage stability optimistic in static load and pessimistic in RE. It is well known by measurement that existing static load (excluding induction motor) shows almost constant admittance character. Also it is well known in measurement and experiment that RE shows almost constant current character, but shows near constant admittance character (with smaller output) during and after voltage sag. Therefore there is some reason for expressing RE as fixed admittance.

Power flow at standard condition when power of induction motor load is Pm + jQm = 0.5 + j 0.05, power of static load is Pz + j Qz = 0.5 + j 0, and RE output is Pre + j Qre = 0 + j 0, is shown in Table 1.

Table 1 Power flow at the standard condition

Vi	Xi	Vg	Xg	Xs	Vs	Xm	Vm
1.105174	0.25	1.02	0.25	0.25	1.0	0.25	0.98

Xm	Rm	Gz	Bz	Bs
0.190178	1.901782	0.520616	0.116682	0.14838

Active power of synchronous generator is Pg = 1.0 at standard condition. When active power of RE increases 0 to Pre, Pg is reduced to Pg = 1.0 – Pre. Then, reactance Xi and Xg increases as inversely proportional to Pg, and expresses the situation that synchronous generator is replaced by RE. Although power flow condition varies, voltage Vg, Vs, and Vm are maintained by adjusting Vi, Bz, and Bs. RE employs constant leading power factor Qre/Pre = -0.2 for reducing voltage deviation in distribution network.

Torque-Speed Curve When Vm = 0.98, induction motor's active power is Pm_0 = 0.5 (p.u.). In the condition, assuming motor speed is n_0 = 0.975 and resistance is Rm_0, resistance Rm at speed n is $Rm = Rm_0 (1 - n_0) / (1 - n)$. Electric input torque Te is equal to active power Pm. Mechanical output torque Tm is assumed to be proportional to powered speed n2, and expressed as $Tm = Pm_0 (n/n_0)^2$.

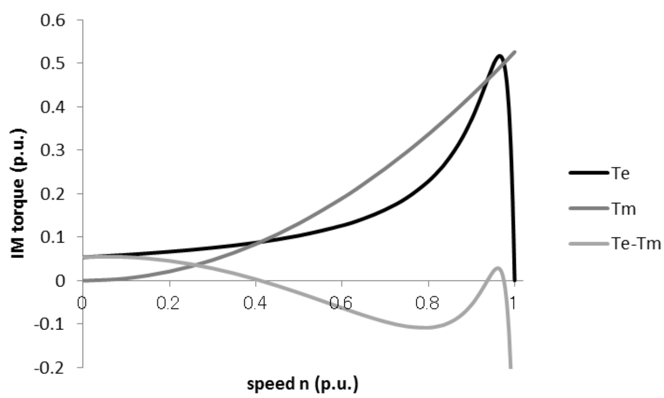

Fig. 2 Torque-speed curves at the standard condition

When motor speed n varies in standard condition, Te, Tm, and acceleration torque Ta = Te – Tm are calculated as fig. 2. Region showing positive Ta barely exists at slower side of n_0 = 0.975, and voltage stability is poor.

Then, some synchronous generator is replaced by RE. Torque-speed curves are calculated as Fig. 3 for some Pre cases. When Pre is -0.4, voltage stability is threatened. When Pre is -0.6, voltage stability is lost.

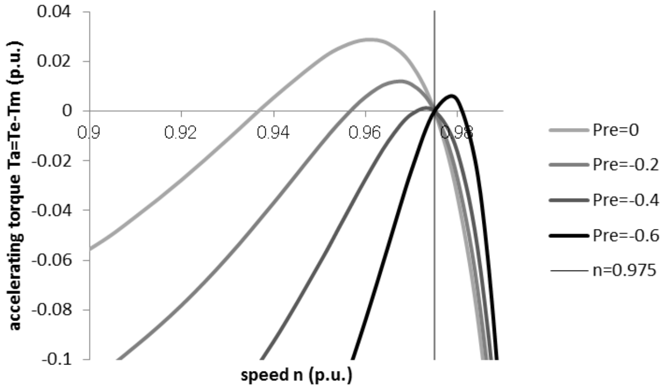

Fig. 3 Torque-speed curves by RE output

So long as RE does not have own unique AC phase and is controlled to follow system phase, RE is no more than a negative load, and cannot be called power source. When synchronous generator is replaced by RE, induction motor load goes to unstable sooner or later.

Only way to avoid the voltage instability is to equip RE own unique AC phase. For example, concept of vertical synchronous machine exists. The concept is already half built in hydro power station simulator(10)(11) for training, as introduced in the former chapter.

Analysis here is very simplified on 1 machine 1 load system model. Detailed analyses considering dynamics of synchronous machine and excitation system may bring different unstable phenomena. Of course father research is needed, and since research based on simulation cannot clarify mechanism of undesirable phenomena, analyses by manual calculation here is needed and also it is needed to maintain level of mathematics, physics, and electric engineering.

Merit of Forgiving Frequency Rise

Since power system AC system, to be maintained are voltage and frequency. Maintaining voltage is stated in the former section. The section deals frequency. LFC (Load Frequency Control) is one of the successful controls in power system. Frequency deviation is managed so small as 50±0.2Hz or 60±0.1Hz even in Japanese small interconnection.

Let us evaluate the accuracy of 50±0.2Hz. Frequency ratio of semitone in music is $2^{1/12}$ = 1.05946, while frequency ratio of 50.02 Hz and 50Hz is 50.02/50 = 1.0004. The latter is only 1/149 of the former. Certainly belt-driven analogue disc player varies its rotation speed due to system frequency, but even a very keen musician cannot detect pitch deviation when system frequency is maintained as 50±0.2Hz. In addition, time deviation that is time integral of frequency deviation also so well controlled that error of electric clock is quite suppressed.

However nowadays, audio equipment is driven by servo-motor, electric clock is replaced by radio clock, so small frequency deviation matters very small. Most electric equipment allows frequency deviation 5% including synchronous machine. So, to allow small frequency deviation can support to make RE as trunk power source. Under-frequency should be avoided, because such protection as opening tie line, but over-frequency does not bring such serious harm.

Types of Governor Operation Speed governor is indispensable for maintaining system frequency. There are some types of governor operation and show different frequency regulation. Typical governor operations are introduced in Fig. 4. Conventional power source equips one of them. Frequency regulation δ is chosen as 0.04 or so. Since maximum guide vane mouth is 1.2 at most, system frequency never rise 5%. For the purpose governor of conventional power source is designed. To know types and characters of various governor operation can contribute to make RE trunk power source. Three types of governor operations are demonstrated hereafter using fig. 4.

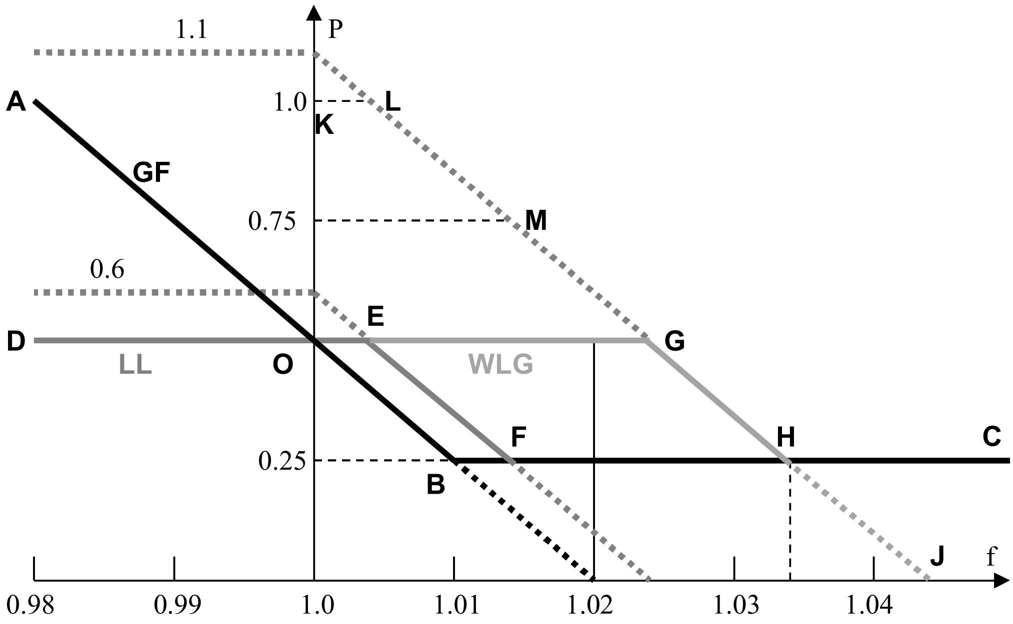

Fig. 4 Power-frequency character of speed governor

(1) Governor Free Operation (GF) Generator operates at reference frequency 1.0 and output 0.5 (p.u.) now. As frequency decreases operation goes O to A, and output increases. As frequency increases, operation goes O to B to C. Output decreases but is kept minimum decided by limit of boiler between B and C. Usually, speed regulation, which is relationship of output and frequency, is 4%f / 100%P, that is, 100% output change is generated by 4% frequency change. GF is used in reservoir hydro generation and gas thermal generation.

(2) Load Limiting Operation (LL) Load limiter is assumed to be set as present output 0.5 plus 0.1, that is 0.6. As frequency decrease, operation goes O to D. Output does not increase. As frequency increase, operation goes O to E to F to C. Output decreases but not so much as GF. Section F to C means minimum output due to boiler and et. al. LL is used in atomic nod coal thermal generations.

(3) (Water) Level Governor Operation (LG) (Water) level governor is used mainly in natural inflow hydro generation. Output reference (called as 65P in Japan) is set as maximum turbine mouth, 1.1 n Fig. 4. Load limiter (called as 77M in Japan) makes the mouth width to maintain head tank water level suitable. As frequency decreases, operation goes O to D, as same as LL. As frequency increases, operation goes O to G to H to C. LG does not begin to decrease output until frequency rise more than LL case, but, ignoring minimum output, output goes to zero at frequency 1.044.

LG is employed in RE as a worldwide standard. Since RE is not constrained by minimum output, as frequency decreases, operation goes O to G to H to J. However, this LG function of RE is not used only in Japan.

Numerical Example LG function on RE is evaluated by numerical calculations. For demand 1.0, RE with rated output 1.0 operates at 0.5, power system generator with rated output 1.0 operates at 0.5. That is, power system has sufficient reserve so that no outage occur even if RE output goes to zero. Power system generator operates in LFC. Here supposed that RE output increases to 1.0. Power system generator decrease its output to minimum 0.25, but supply exceeds demand by 0.25.

(1) RE is Constant Output Operation Excessive supply 0.25 is absorbed by load increase due to frequency rise. It is observed that load increase 2% by 1% frequency rise. For increasing 1.0 demand to 1.25 (25% increase), frequency must rise 25%P * (1%f / 2%p) = 12.5%, and frequency rise to 1.125 (67.5Hz in 60Hz system). Such significant frequency rise must not be allowed.

(2) RE is LG Operation Assuming that load does not increase due to frequency rise, RE operation goes K to L to M. Assuming speed regulation of RE is 4% and load's frequency sensitivity is 2%P / 1%f, frequency rises to

$$1.004\ (L) + 0.25 / (1/0.04 + 2) = 1.01326$$

This is 60.08Hz in 60Hz system. Even if RE output increase is such extreme one, frequency rise is mitigated to only 0.8Hz. Therefore, it must be hurried to make available RE's LG function. Of course it is troublesome that frequency very often rises to 60.8Hz, but, it must be agreed that small frequency rise is permitted in excessive supply scene. Bu such power system operation, power system generator can possess sufficient reserve without considering excessive supply, and shortage of reserve due to sudden decrease of RE output can be avoided. It is mandated that slightly excessive power source is employed and reserve is more carefully treated than excessive supply.

In addition, grid code in Japan was not made without joining those who understand power system well, so must be remade as soon as possible.

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Postscript

The author has been astonished, because results by extended classic analysis methods based on simply aggregated power system model has given almost same results by modern simulation tool on detailed power system model. Predecessors who could not use modern simulation tools were forced to develop and use classic analysis methods, which are proved quite adequate if correctly used. Those classic and extended classic analysis methods can give engineers insights, which modern simulation tools cannot. Further saying, only those who use classic analyses methods have qualification for performing simulation, because simulation without physical insights always has risk for mistaking and overlooking the mistake. However, in spite of its importance, classic theories are going to lose their initiators. *Buddhism* had predicted such a condition of itself as *Mappo*, which means decline of the doctrines, dieing out of initiators, and only remaining of the *Scriptures*. *Buddhism* had also predicted that *Mappo* would go worse to *Meppo*, which means complete ruin of the doctrines and the *Scriptures*. The author has published the book as a *Scripture*, and hopes that it will survive as long as possible in *Mappo* era of electric power system engineering.

By the way, why such an important technology is going to ruin? One reason is thought that accomplishment of simulation tools has reduced importance of classic theories. Since everybody will believe simulation result, engineers do not necessarily have to know theories and physical meanings, only if simulation runs to the end. By *Confucian* criticism, simulation technology has ruined engineers who developed it. Thus, simulation is in all its glory today. But let us think a little while. Simulation tools does not run and give answer if users do not put in numerical data. Users are not always expert engineers, but only masters of TV game named simulation and inhabitants of virtual reality of simulation. It is quite possible that users cannot examine the adequacy of model and data to be put into the tools. In such a condition, who can rely on the answers given by such simulations? Those who trust upon them might be sleeping on volcano mouth.

Electric power system is metamorphosing. Today’s adequate model and data cannot always be adequate in tomorrow. The author think that now is the metamorphosing period. Two main incidents are progressing. One is retirement of aged thermal generation. Another is penetration of distributed generation. Both of the two will reduce load’s voltage stability, and as the results, reduce transient, dynamic, and frequency stability of interconnection. Traditional model and method have been proved not to tell the truth but to overlook and mislead. As the countermeasure, the author has introduced new model and method. The results were astonishing. Besides, although everybody understands that high penetration of RE whose output fluctuates by time will threaten voltage and frequency regulation in power system, quantitatively analyses seems to stagnate, therefore, the author by himself clarified. The contents were published as paper and introduced in the book.

It is “Science of Philosophy” that understand why natural science has achieves such fine success. Science has its unique and brilliant method. To do along with scientific way is very likely to complete account responsibility. However in recent Japan, those who are regarded as scientists sometimes tell what are not scientific. Instant decision as active fault in nuclear plant by “Nuclear Regulation Committee” is typical, and members seem not to complete account responsibility for utilities and self-governing bodies. But the criticism can be also applied to utilities. Have utilities taken scientific approach and completed account responsibility for an example in problems on RE integration? Among utilities, the author has continued to be scientific. Research fruits have been published as paper with peer review. Peer review is a strong proof that distinguishes those papers from pseudo-science. Announcement by private publishing or technical report without peer review is not validated and sometimes brings useless misleading. Therefore, paper with strong impact must be published as paper with peer review. Although utilities are mainly not sender but receiver of information, they should know the difference between papers (with peer review) and private publishing or technical reports.

Contents dealt in the book are not in high level and not difficult. Ordinary scientists must reach the destinations. Then, why numerous employed scientists cannot reach the destinations before the author? It has been a question for the author long. However recently, it was recognized as possible as follows. That is, employed scientists do not like that now going research theme finishes. More epoch-making the research is, the research becomes higher "destructive creation", which makes past efforts including outskirts nothing. By "destructive creation", now going research come to its end and scientists must transfer another theme to live. Considerable effort will be needed. Treatment of employed scientists became worse than ever. Employment with period became ordinary. If the theme finished, extension of employing period may vanish. Therefore, the sense that available time of the theme should be made as long as possible can be understood. But it is national loss. They are non-employed scientists who break such sabotage by employed scientists. Of course, employed scientists oppose to new theories and so on. Contents of the book were also opposed. In Japan, the book may be burned like *Giordano Bruno*. Therefore, this English version is made. In near future, when the country will be in need, these technologies can be reverse-imported. That is *Kurofune* operation. Thus now, the book is uploaded in the author's site.

3.11 Fukushima 1 nuclear meltdown and JR west Fukuchiyama line derailment brought much poison to society. Even if organization brought artificial disaster for profit-making, nobody is punished. Such punishment operates as deterrent, which is not hoped today. Under such condition it cannot believed that most people support reoperation of nuclear power generation. For people's support, something such as "organizational disaster punishment law" must be established. In case of 3.11, Higashidori, Onagawa, Hukushima 2, and Tokai 2 nuclear power stations could escape from the tsunami disaster, because they had made various improvements before the disaster. Some reason must exist why only Fukushima 1 went to meltdown. The reason is not explained by organization nor the utility, and all nuclear power station is equally dealt, thus people deny all nuclear power station equally. The author thinks that unique sin of Fukushima 1 must be clarified.

The book is *Cassandra*'s prediction. Prediction never works if the two conditions are not fulfilled. The first is to realize. The second is to be believed. *Cassandra*'s prediction lacked the second condition. Thus, *Troy* lost out to *Greece* and became a ruin. However, even *Cassandra*'s prediction may be believed outside of *Troy*. And ruin of *Troy* may be discovered by *Schliemann*. Really, the *Cassandra*'s prediction is already spreading in the world as US as the first. In near future, it will become new standard of electric power system engineering. Then, for honor of Japanese engineers, the author intends to leave some evidence that these studies ware performed in the past, although the fruits were executed by fire or buried underground. That is a small hope of the author.

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An obscure electric engineer

Shintaro Komami