11. Strategy for High RE Penetration

Is Carbon Free Power System Possible?

Although it is true that most important condition of RE's high penetration is their economy, it is considerably important condition among the others is that RE can be integrated into existing system without problem or inconsistency. Low reliability is not acceptable even if economy is splendid. It seems wise to assess at the beginning whether carbon free power system with no thermal power stations is possible or not.

Thermal generators take two important roles. The first is reserve, which is classified from spinning reserve supplied by generators operating at partial output to stand by reserve supplied by stopped but warm generators, and energy reserve or kWh reserve is supplied only by thermal generators. If kWh reserve is supplied by batteries, cost may be gigantic. On the contrary, reserve can be economically prepared by good power system operation.

The second is system voltage support. Since thermal power stations can site near load center, they are the main body to support power system voltage. When such important generators stop at all, even if REs have DVS capability, voltage support capability of whole system will considerably decrease. What may follow? And what are effective measures? Those are main theme of the chapter. If voltage support capability is short, much amount of additional equipments such as SVC may be needed.

How serious is the voltage support problem? It may be effective to assess voltage support capability in condition that all thermal generators are stopped and that power shortage is fulfilled by nuclear power, RE, and battery so as to demand supply balance is maintained. As follows, four systems that seem to have voltage support problems are studied.

[Carbon Free System 1] Structure of the system is shown in Fig. 9.1. Coal fired thermal generator G4 is scrapped. Nuclear generators G9 and G10 are newly built. Batteries B1 and B2 are added for maintaining demand supply balance. All REs and batteries are assumed as having DVS capability. So long as seeing power flow network needs no reinforcement. Generator G6 was mixture of large thermal generator and local hydro powers, and the thermal power station is scrapped, but only generators are reused as rotary condensers (RC) for keeping voltage support capability.

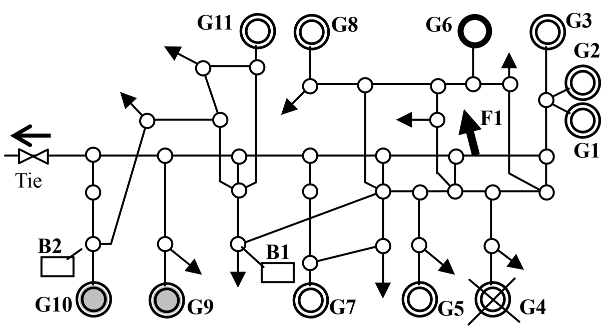

Fig. 9.1 Structure of carbon free system 1

6LG-O fault is assumed on 2-circuit 500kV transmission line at F1. Fault duration time is set as 0.07 sec. Heavy power flowing the 500kV line shifts to 275kV network. Since Transient synchronous stability is threatened, generator G1 is shed at 0.25 sec after fault occurrence.

Simulation results are shown in Fig. 9.2. The system maintains stability with RC. However, the RC is omitted, generators G2 and G3 go to asynchronism as shown in Fig. 9.3. Generator G6 has an importance role because only little power sources exist around it.

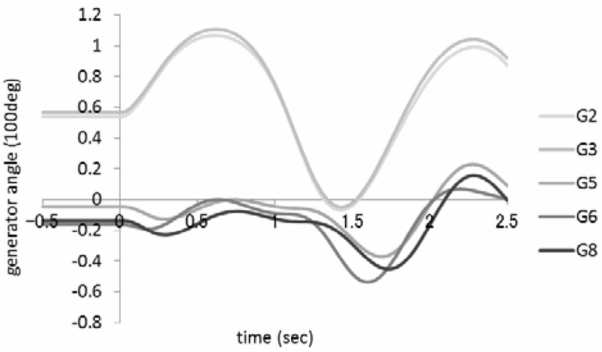

Fig. 9.2 Stability of carbon free system 1 (with RC)

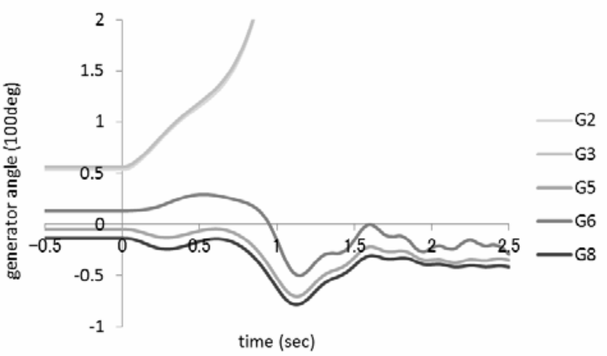

Fig. 9.3 Stability of carbon free system 1 (w/o RC)

[Carbon Free System 2] Structure of the system is shown in Fig. 9.4. Nuclear generators G1 and G2 are newly built, G3 and G4 are reinforced. 9 thermal generators are reused as RCs. The system has considerable amount of pumped storage, and no batteries are needed for demand supply balance. 500kV/275kV transformers are added in needs.

A 1 circuit 3LG-O fault on 2-circuit 500kV transmission line is assumed at F1. Fault duration time is set as 0.07 sec. Deep voltage sag due to the fault spreads to wide area and loads partially drop.

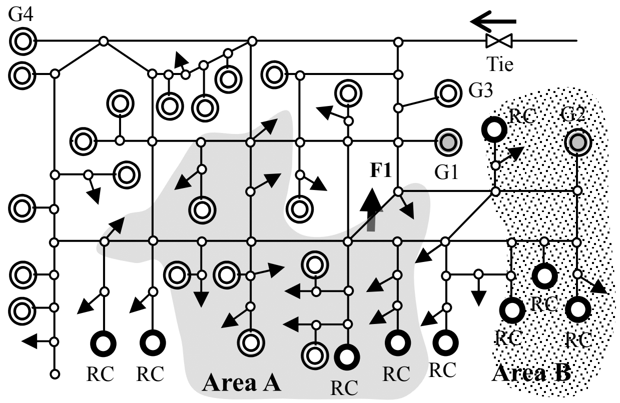

Fig. 9.4 Structure of carbon free system 2

Simulation results are shown in Fig. 9.5. By contribution of the 9 RCs, load voltages recover even though slowly. However, when 9 RCs are omitted, load voltages cannot recover as shown in Fig. 9.6.

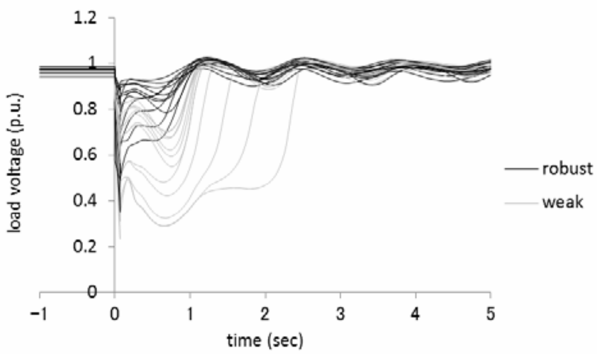

Fig. 9.5 Stability of carbon free system 2 (with 9 RCs)

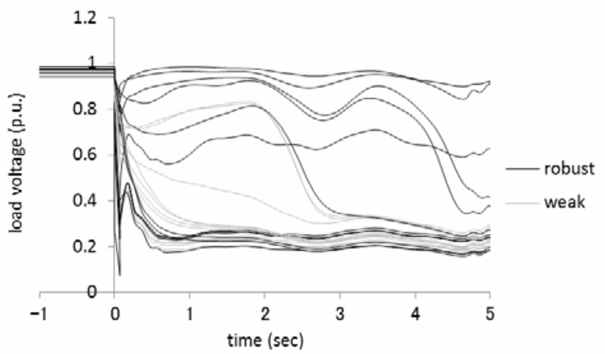

Fig. 9.6 Stability of carbon free system 2 (w/o 9 RCs)

By the way, power sources of area B were thermal only. If new nuclear G2 cannot site in the area and nuclear G1 is reinforced instead, area B suffers from power shortage, and goes to voltage instability in spite of the 9 RCs as shown in Fig. 9.7.

It is favorable power source and load are well balanced with in an area. Some people say that electricity should be generated locally and consumed locally. From viewpoint of electric engineering, their opinion is perfectly correct. In Japan, criteria of wide area electricity trade are not decided by natural laws made by gods but by social laws made by people. Some disasters must occur in near future because of neglecting natural law made by gods.

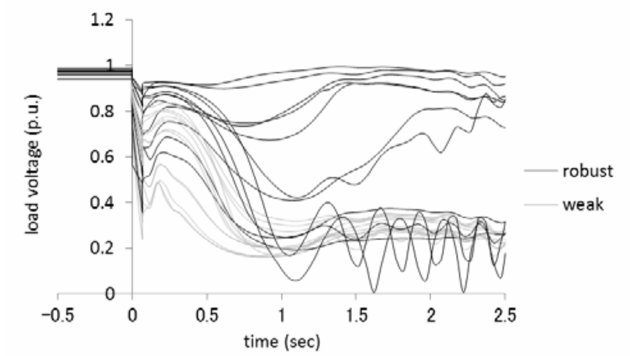

Fig. 9.7 Stability of carbon free system 2 (w/o G2)

[Carbon Free system 3] Structure of the system is shown in Fig. 9.8. Nuclear G1 is reinforced. Large thermal G2 at 275kV is rebuilt as nuclear. Large thermal generators in G3 and G4 are retired and local hydro generators only remain. Two thermal generators are reused as RCs. Since nuclear increase, 6 batteries are added in trunk system for demand supply balancing.

By change in power source distribution, power flow turn rightward to leftward. Some 500kV/275kV transformers are reinforced due to increased power flow.

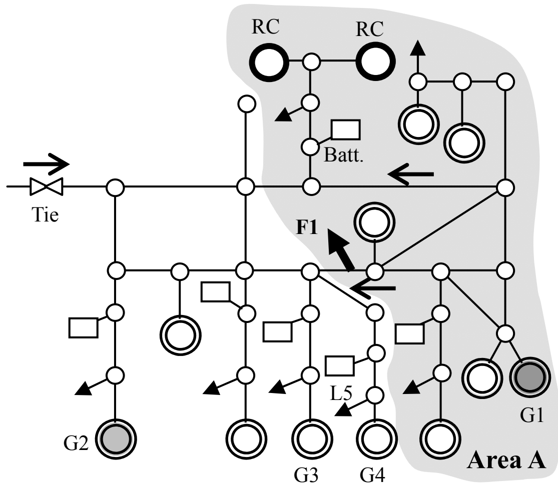

Fig. 9.8 Structure of carbon free system 3

A 6LG-O fault on 500kV 2-circuit transmission line is assumed at F1. Fault duration time is set as 0.07 sec. End of the system (area A) that is shown in the figure as the right end with gray background and that was sending much power leftward has lost one of two routes and its stability is threatened. Simulation results are shown in Fig. 9.9. Generators and loads in area A are distinguished as gray lines. Load L5 outside of area A shows slow voltage recovery, because its nearby thermals are scrapped and voltage support became weaker.

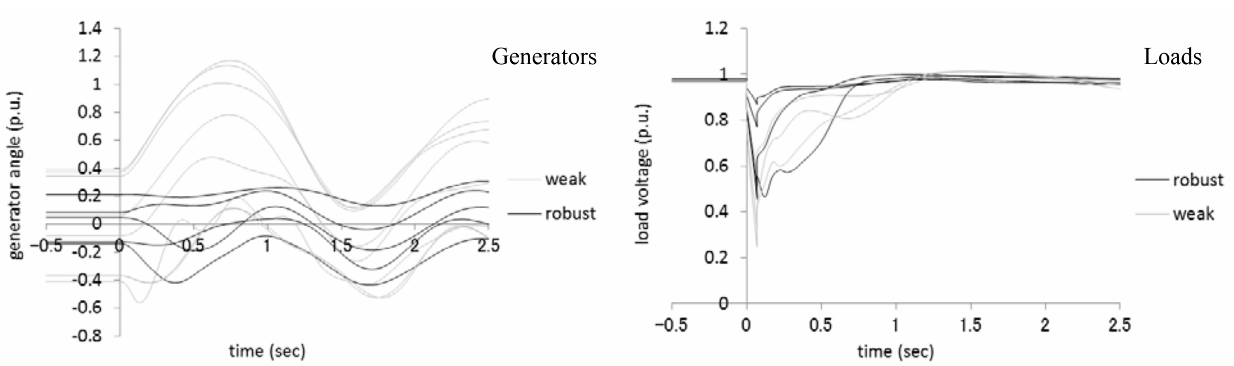

Fig. .9 Stability of carbon free system 3 (with 2 RCs)

2 RCs bear an important role to support voltage at the midway of long and thin system created by the fault. Simulation result without the important 2 RCs are shown in Fig. 9.10 All generators in area A go to

asynchronism, all load in area A go to voltage collapse, and in addition, load LF outside of area A goes to voltage collapse.

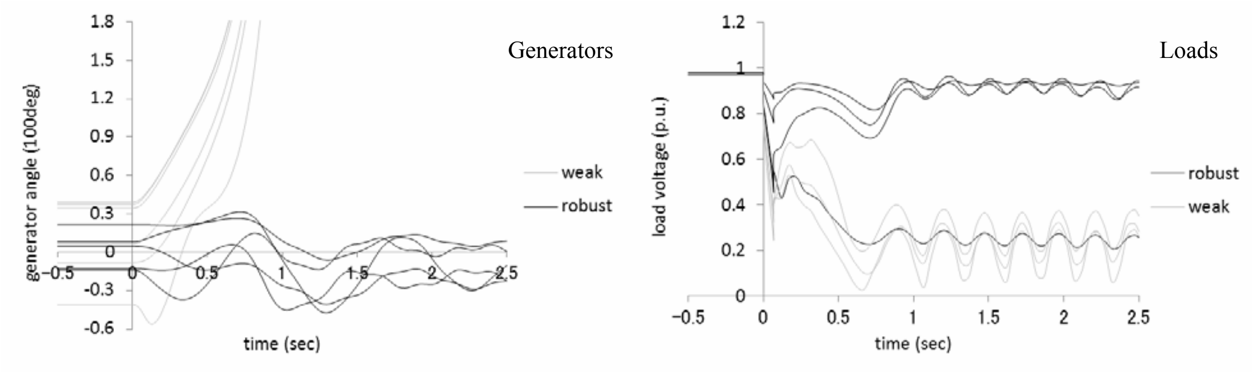

Fig. 9.10 Stability of carbon free system 3 (w/o 2 RCs)

[Carbon Free System 4] Structure of the system is shown in Fig. 9.11. Thermal G1 and G2 is scrapped. Thermal generators in G1 and G2 are also scrapped. Thermal generators in G5 and G6 is reused as RCs. Nuclear G7 is newly built. 3 batteries are added in trunk system for demand supply balance. Some 500kV/275kV transformers are added because of increased downward power flow.

Power supply in Area A is insufficient. Area A receives much power from outside. Area A had much thermal power sources in G2, G5, and G6. However, G2 is scrapped, and Generators in G5 and G6 only remain as RC. By batteries having 10% capacity of load, power supply shortage is somewhat mitigated.

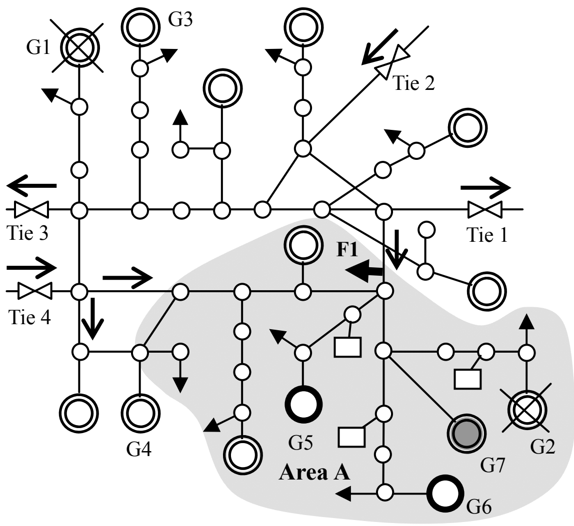

Fig. 9.11 Structure of carbon free system 4

A 2-circuit 6LG-O fault is assumed on a 2-circuit 500kV transmission line at F1. Fault duration tine is set as 0.07 sec. One route for receiving power from outside is lost and stability of area A is threatened.

Simulation results are shown in Fig. 9.12. Synchronous and voltage stabilities are maintained. Voltage recovery delay is a little slow but better than very slow recovery of “Carbon Free System 2”.

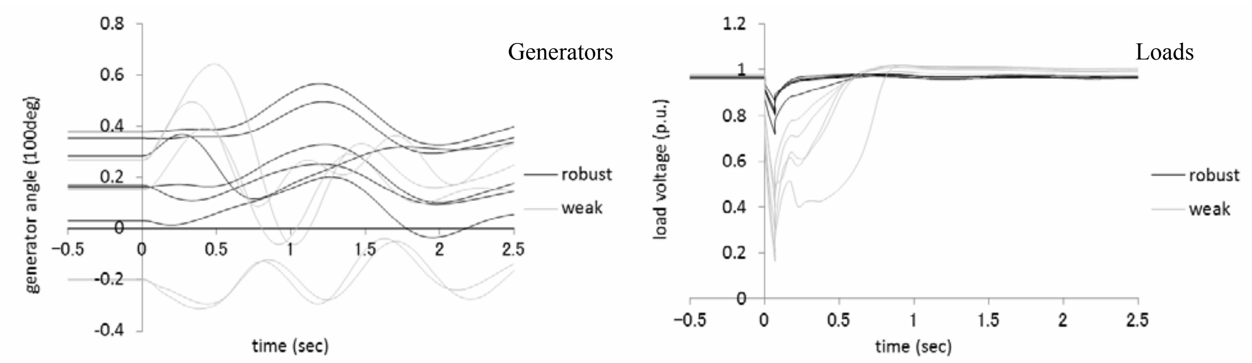

Fig. 9.12 Stability of carbon free system 4 (with 2 RCs)

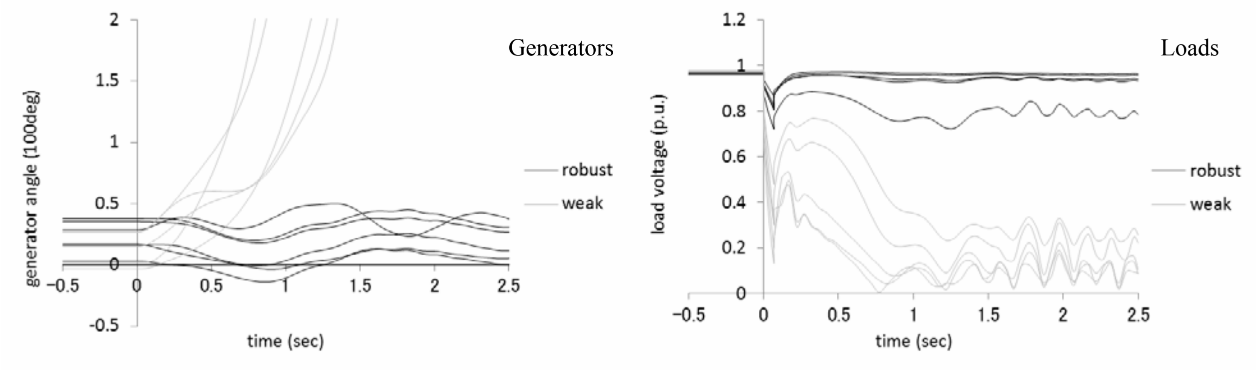

Fig. 9.13 Stability of carbon free system (w/o 2 RCs)

Since RCs in G5 and G6 bear important role to support voltage of area A, stability is lost if those RCs are scrapped. Simulation results are shown in Fig. 9.13. All generators in area A (weak) go to asynchronism and all loads in area A (weak) go to voltage collapse.

How readers think about the four examples? Carbon free power system may seem to be a fiction, and newest pessimistic knowledge such as IM load and network impedance to load terminal may deny the reality. However, carbon free system in not impossible for today's science and technology. Readers may rely on science and technology themselves more. However, it may be indispensable to purge and rebuild leaders and education stuffs in electric power engineering field, to invite excellent juniors to our field, and to make a restart.

Super DVS on RE

Thus, if all REs have DVS capability, and if some thermal generators are reused as rotary condensers, carbon free power system is possible. DVS function used here is similar to SVC, and the function can be reinforced like SVG, and number of RCs can be reduced. A utility in Japan is studying more powerful super DVS that supplies short circuit current during fault. For the purpose, more robust element than now used IGBT becomes needed. Increased short circuit current in distribution network must be considered. Much investment may be needed. The author regards supplementary voltage support devices such as RC and so on are conservatively hopeful. However, technology around power system may be changed in those days when RE really penetrates much, therefore, prejudice must be forbidden.

DVS function assumed in chapter 4, 5, and 6 is designed like SVC, and assumed to have reactive power-voltage characteristics like parallel composite of capacitor and saturated reactor. The type of DVS is called as "impedance type" hereafter. For avoiding over current of interconnection equipment, active power is assumed to be controlled as proportional to square voltage. Characters stated above are expressed by equations as follows.

$$P = P_0\,(V/V_0)^2$$
$$Q = W_0\,[(V/V_0)^2 - V/V_0)^B]$$
$$B > 2$$

Since existing RE's power conditioner system (PCS, interconnection equipment) is built by IGBT, more powerful voltage support PCS named "current type" can be realized. The characteristics are expressed by equations as follows.

$$P = P_0\ (V/V_0)^2$$
$$Q = W_0\ [(V/V_{0)}^1 - V/V_0)^C]$$
$$C > 2$$

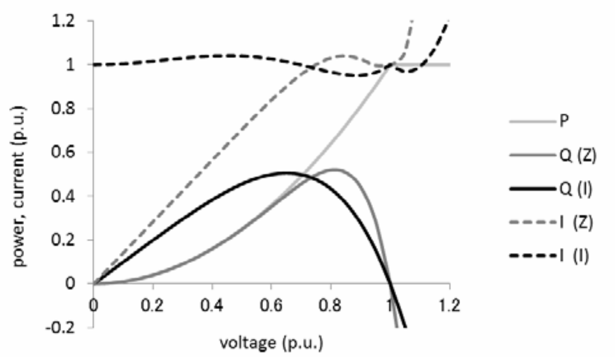

Fig. 9.14 Characters of impedance type and current type

Characters of impedance type with B = 9.5 and that of current type with C = 4.5 are compared in Fig. 9.14. Peak value of reactive power is almost same, but current type can supply more reactive power at lower voltage region. At low voltage region, PCS current becomes smaller in case of impedance type, but does not decrease in case of current type. Current type uses PCS capacity more thoroughly and usefully than impedance type. When voltage is 1 or more, PCS current exceeds 1. This is caused limitation of simulation tool. Of course in real PCS, such overcurrent is avoided by control. However, stability problems occur when voltage is lower. Such slight incorrect modeling can be ignored.

[Synchronous Stability in Power Sending System] In the power sending system introduced in chapter 5, synchronous stability with impedance (Z) or current (I) type DVS is examined, and the results are shown in Fig. 9.15. Fault duration time is taken as parameter. Current type and 0.08 sec clear case is more stable than impedance type and 0.08 sec clear case, but less stable than impedance type and 0.07 sec clear case. That is, current type shows better stability than impedance type, but the difference is smaller than 0.01 sec of fault duration time.

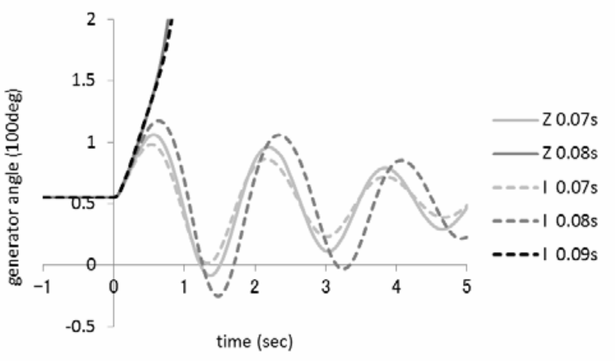

Fig. 9.15 Stability with impedance & current type (send)

[Synchronous Stability in Power Receiving System] In the power receiving system introduced in chapter 5, synchronous stability with impedance (Z) or current (I) type DVS is examined, and the results are shown in Fig. 9.16. Fault duration time is taken as parameter. Current type and 0.08 sec clear case shows almost same stability as impedance type and 0.07 sec clear case. Current type and 0.09 sec clear case is more stable than impedance type and 0.08 sec clear case. That is, current type shows better stability than impedance type, and the difference is larger than 0.01 sec of fault duration time.

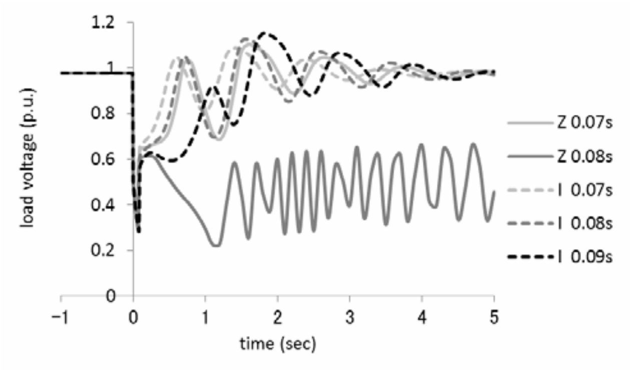

Fig. 9.15 Stability with impedance & current type (receive)

As shown above, DVS used in former chapters operates in light duty, and can be more effective for improving system stability if PCS capacity is fully used. In addition, current supply during fault is not adopted here, but the current supply can mitigate voltage drop during fault and slightly improve stability.

Measures for Frequency Deviation

Issues in large geographic area such as interconnection are demand supply balancing and frequency deviation. Measures as follows seem effective by studies above.

[**Regulation Battery**] Regulation function in LFC can be sufficiently achieved. Its cost can be calculated as follows. Daily maximum demand in light demand period is almost 120GW in Japan. For regulation ±1% capacity of peak demand as follows will be needed.

120GW * 0.01 = 1.2GW

Since regulation compensates fast fluctuation, 0.2 hr duration of battery will be sufficient. That is,

1.2GW * 0.2hy = 0.24GWh

For fast charge and discharge, not NaS battery but Lithium ion battery is suitable. Unit price of converter is assumed as 30k¥/kW, and that of battery is assumed as 200k¥/kWh. Then, total price becomes as follows.

1.2GW * 30k¥/kW + 0.24GWh * 200k¥/kWh = 84G¥

The price is quite lower than the price that was thought as needed until today for another approach “reserve battery”

“Reserve battery” approach assumes that output of thermal generator 30% to 40% of rated power for keeping negative reserve, and excessive energy is stored in battery. Supposing 20% of 120GW peak demand is borne by thermal generators and storage is needed 5 hr in a day, necessary amount of battery is calculated as follows.

120GW * 20% * (40% – 30%) = 2.4GW

2.4GW * 5hr = 12GWh

Unit price of converter is assumed as same of the former case, 30k¥/kW. As battery, economical NaS battery is available. Its unit price is assumed as 40k|/kWh. Then, total price is calculated as follows.

2.4GW * 30k¥/kW + 12GWh * 40k¥/kWh = 5520G¥

Thus, new idea "regulation battery" is more economical than old idea "reserve battery". However, it must be remembered that "reserve battery" has not only regulation but also a certain load following capabilities. "Regulation battery" depends load following on reservoir and pumped hydro power stations. In addition, both batteries cannot absorb power/energy in some periods with low demand and excessive supply. In such a scene, not only thermal power but also low carbon power must be curtailed.

Since RE and the other low carbon power sources have the same priority as "low carbon", they should be curtailed evenly. From viewpoint of public safety, curtailment in hydro power becomes problem. Water flown in waterway turns to flow in the river, where human may be working (such as fishing). That is risky. As natural power, wind and solar power can be curtailed more safely. Nuclear power can also curtail although its ramp rate is limited. From viewpoint of control cost, curtailment of small and many solar powers is not economical. Control cost of remote-controlled hydro power, wind power, and megasolar or human controlled nuclear power will be lower.

Wisely thinking, curtailment of nuclear power seems attractive. However, utility must buy the curtailed amount of energy from solar or wind power with extraordinary high price. Is it fair? RE price must be reduced to adequate level when utility owned low carbon power source is curtailed. If the price is such level that compensates control cost increase when control object is changed from utility owned generators to REs, it may be acceptable. To pursuit total optimal, making adjustment such as adequate price is the role of regime and law, so the author thinks.

[**RE Output Prediction**] Demand prediction is indispensable for good load following. By experience of author at central dispatching office, RMS error in next day demand prediction is around 2% of peak demand. If annual peak demand is 5000MW, absolute RMS error is calculated as follows.

$$5000MW * 0.02 = 100MW$$

RE assumed to penetrates by 30% of peak demand. If RMS absolute next day prediction error of RE output is equal to that of demand, relative error in next day RE output prediction becomes as follows.

$$0.02/0.3 = 0.067 = 6.7\%$$

The RMS error is not on point RE output prediction but on area total RE output prediction. Generally, latter error is considerably smaller than former error. For minute assessment more studies are needed, but roughly saying, such accuracy seems critically possible for today's technology.

Today's RE output prediction methods are based on weather forecasting informations. Some heuristics are added for good accuracy. However, prediction accuracy much depends on accuracy of weather forecasting. By using today's methods, RE output prediction error becomes more troublesome than demand prediction error, as RE penetrates. Before such scene becomes true, some accuracy improvement in weather forecasting becomes needed. It seems a wise way and to indicate the time of necessity is a role of system operators.

[**Flexible Operation of Thermal Generator**] In low carbon era, main role of thermal generator will become regulation and reserve, even in case of coal fired thermal generator, which has been recognized as base power supply because of its low fuel cost. Until today, restarted thermal generator must experience full power operation during several hours if it restarted cold condition. Thermal generation sector engineers say that the purpose of the full power operation is certifying that full power operation is possible. However, lasted full power brings shortage of negative reserve. In addition, what measure exists if it is found that the generator cannot operate at full power? Therefore, these inflexible thermal generator operations must be overcome in low carbon era when RE highly penetrates.

In thermal generators output bands exist by difference in number of supplementary machines for example. When ordered output change crosses band boundary, considerably long constant power operation is forced. In addition, full power test run is held when new coal is used. These numerous restraints in thermal power generation strongly hinder smooth system operation. The author proposes that thermal generation sector should begin research for flexible operation. But they refuse.

Measures for Synchronous and Voltage Stability Problems

Geographically middle sized system issue that appears in several prefectures is power system stability issues. Measures as follows seem hopeful by studies above.

[High Low Mix] The words were used as combination of deluxe F-15 combat aircraft and economic F-16 of US air force in the last quarter of 20^{th} century aiming both performance and economy. Of course, high means F-15, and low means F-16. Here, high means DVS type RE and low means FRT or drop type RE. In studies in chapter 4, 5, and 6, it was found that power system voltage, transient synchronous and oscillatory stabilities with highly penetrated REs become well than those stabilities without REs, if all REs have DVS capability. The results mean that DVS is necessary in not all REs but only partial REs, if system stabilities with REs are not needed to exceed stabilities without REs.

There are some types of active anti-islanding methods that are not compatible with DVS function. DVS is possible only in REs equipped anti-islanding method compatible with DVS, REs equipped remote shut don, or HV-interconnecting REs that are not required ant-islanding methods. Because of total economy, it is not small home use RE but large merchant RE that are required DVS function. That is, DVS function is a kind of “noblesse oblige”. In today’s power system, control equipments are installed in fewer and larger generators for total economy.

High low mix RE system becomes as shown in Fig. 9.17. First, drop type REs are purged out. Small home-use RE interconnecting to LV is required to be FRT type at least. Because, FRT type RE can be realized with small cost-up. Large merchant RE interconnecting to MV is required to be DVS type. How much portion of REs must be DVS type for realizing the same stability of no RE case.

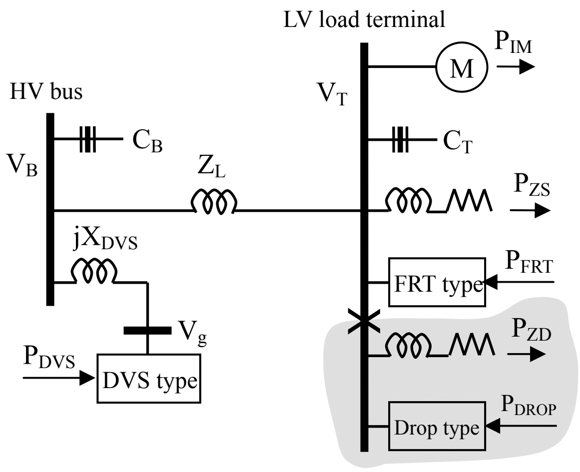

Fig. 9.17 Mixture of drop, FRT, and DVS type REs

In the same time, endeavor by power system side is necessary. It is not fair only RE side bears responsibility of power system stability. Here, as the most effective and economic measure, fast and powerful excitation system on large generators. Usual excitation system can generate around 5 times larger voltage as field voltage of no load generator. Fast and powerful excitation system can generate 7 times or more voltage as that. Japan sea coast area is attacked by quite strong winter lightning. Two-circuit failure on two-circuit transmission line is not rare. If different two phases out of AC three phases survive, high speed reclosing is possible. However, lacking one phase causes severe reduction of transmission ability during the reclosing time, and transient synchronous stability is threatened. Fast and powerful excitation system is often adopted as the countermeasure and has shown successful results. By higher ceiling field voltage, synchronous torque of generator increases. Block diagram of the typical system is shown in Fig. 9.18. Since capacity of exciter is much smaller (a few percents at most) than generator, additional cost is not large. The system can be considered as "noblesse oblige" of utility owned large generators.

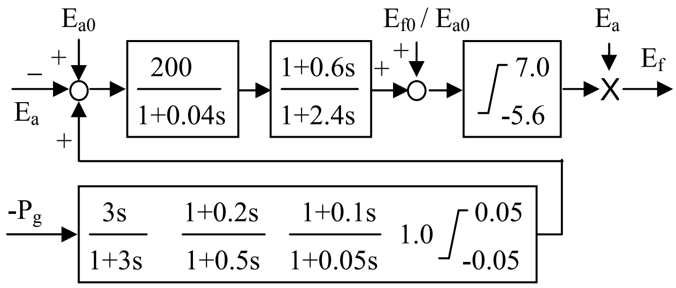

Fig. 9.18 Block diagram of typical fast and powerful excitation system

[Voltage Stability] Example of the large interconnection introduced in chapter 4 is used here. REs generate at their rated power and supply 20% of total loads. Partial load drop due to voltage sag is considered.

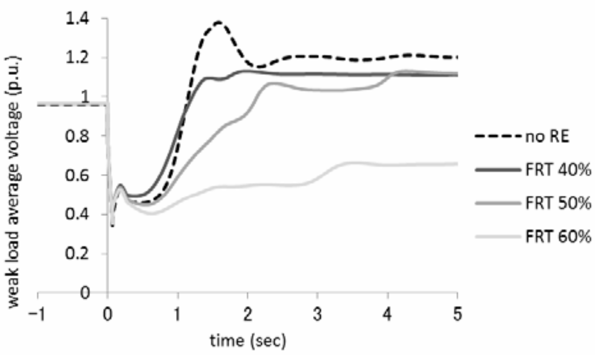

Fig. 9.19 Voltage stability by FRT type percentage (regular)

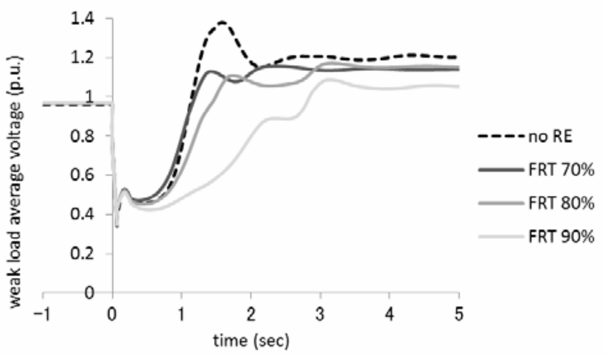

Fig. 9.20 Voltage stability by FRT type percentage (powerful)

As shown in Fig. 9.19, in case of regular exciting system, same stability as no RE case is possible if FRT type is 40% or less (that is, DVS type is 60% or more). When generators in weak load area equip fast and powerful excitation system, FRT type can penetrate up to 70% (that is, DVS type can be reduced to 30%) for the same stability of no RE case as shown in 9.20. By fast and powerful excitation system, FRT type RE can penetrate 30% more than regular excitation system case.

[Transient Synchronous Stability in Power Sending System] Example of the power sending system introduced in chapter 5 is used. REs generate at their rated power and supply 20% of total loads. Partial load drop due to voltage sag is considered. In case of regular excitation system, same stability as no RE case is possible if FRT type is 60% or less (that is, DVS type is 40% or more). Fast and powerful excitation system is equipped in the four generators at right and left ends of central large load. The same stability as no RE case can be realized by 70% FRT type (30% DVS type) as shown in Fig. 9.22.

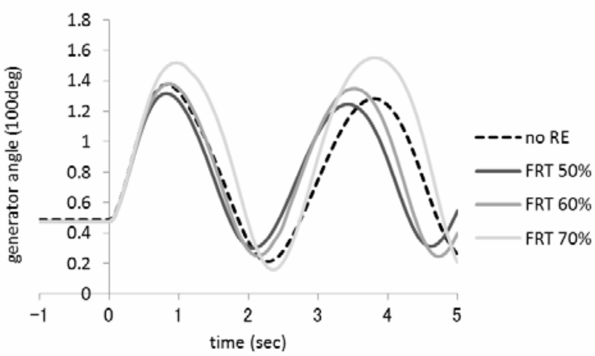

Fig. 9.21 Syn. stability by FRT type percentage (regular)

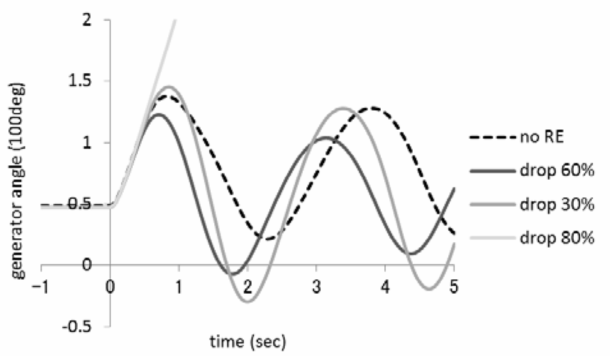

Fig. 9.22 Syn. stability by FRT type percentage (powerful)

[Transient Synchronous Stability in Power Receiving System] Example of the power receiving system introduced in chapter 5 is used. REs generate at their rated power and supply 20% of total loads. Partial load drop due to voltage sag is considered. In case of regular excitation system, same stability as no RE case is possible if FRT type is 20% or less (that is, DVS type is 80% or more). Fast and powerful excitation system is equipped in the three generators in the weak area. The same stability as no RE case can be realized by 80% FRT type (20% DVS type) as shown in Fig. 9.24. By fast and powerful excitation system, FRT type RE can penetrate 60% more than regular excitation system case. Effect of fast and powerful excitation system is significant in the power system. The reason is, perhaps the fact that one generator in the weak area had quite weak excitation system.

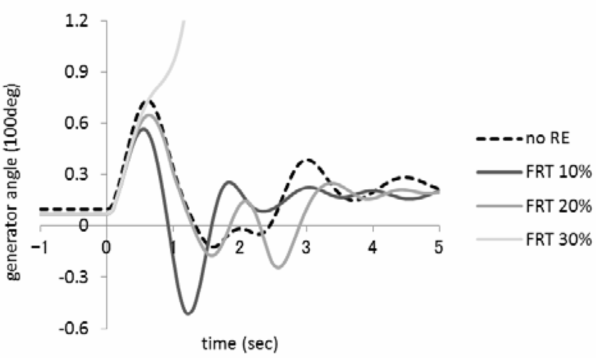

Fig. 9.23 Syn. Stability by FRT type percentage (regular)

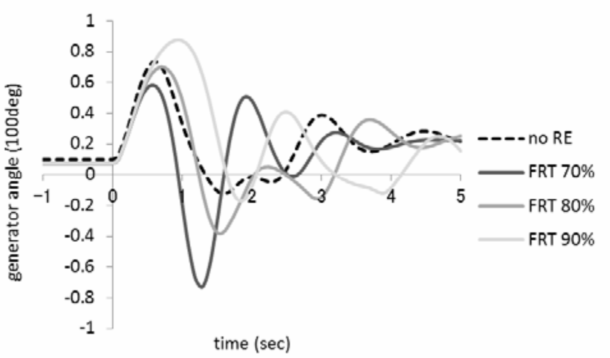

Fig. 9.24 Syn. Stability by FRT type percentage (powerful)

[Oscillatory Stability] As stated in chapter 6, power swing in power receiving system is unique and has different mechanism from regular power swing in power sending system. Therefore also here, sending and receiving systems introduced in chapter 6. Since drop type and FRT type give the same result, the two types are not classified. In addition, since fast and powerful excitation system does not have any effects on oscillatory stability, it is not considered here.

Simulation results in sending system are shown in Fig. 9.25. If FRT type is 90% or less (DVS type is 10% or more), the same stability of no RE case can be realized. That is, only 10% DVS type can maintain oscillatory stability.

Simulation results in receiving system are shown in Fig. 9.26. If FRT type is 80% or less (DVS type is 20% or more), the same stability of no RE case can be realized. That is, only 20% DVS type can maintain oscillatory stability.

In both sending and receiving system, the same oscillatory stability of no RE case can be realized very small portion of DVS type RE. Therefore, oscillatory stability is said as less serious than voltage and transient synchronous stabilities. In addition, oscillatory stability can be significantly improved by adequate excitation system design. Thus, oscillatory stability with RE cam be easily improved and almost automatically maintained if the other two stabilities with RE are maintained.

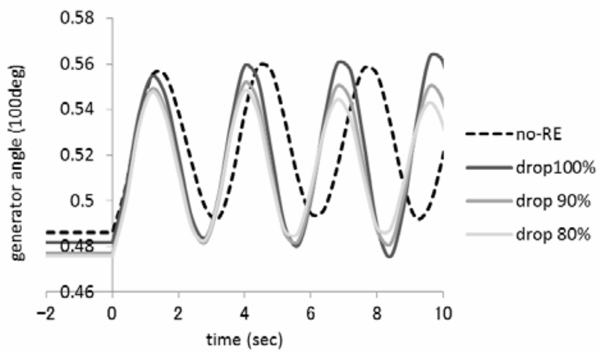

Fig. 9.25 Osc. Stability by FRT type RE percentage (send)

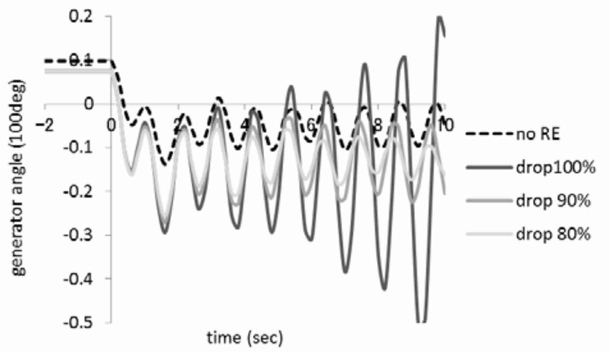

Fig. 9.26 Osc. Stability by FRT type RE percentage (receive)

[How Far RE's DVS Capability Should Be Required?] There are almost no grid codes in the world except E-On (Germany), which is shown in Fig. 9.27. DVS function assumed in the book expressed by reactive current is also shown in the figure. E-ON standard requires supplying reactive current up to capacity limit, and voltage at the condition is 0.5, which seems to be lower. DVS in the book shows steep slope, which means large reactive current change with small voltage change. The character is quite similar to SVC.

By conclusions of chapter 4, 5, and 6, it seems difficult to maintain stabilities with RE to today's level. As compensation, to equip DVS capability on RE seems to be better than to adopt additional SVC. However, DVS is sometimes not compatible with active anti-islanding method. As demonstrated here, fast and powerful excitation system can improve stabilities considerably, and by adopting it, necessary amount of DVS type RE or additional SVC will be reduced.

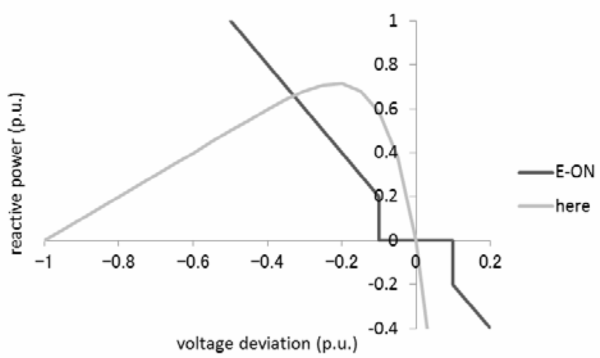

Fig. 9.27 DVS standard of E-On and the book

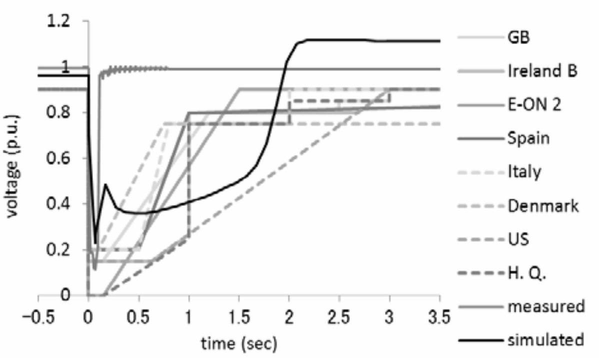

Fig. 9.28 FRT standards of many countries

[How Far RE's FRT Capability Should Be Required?] Many utilities in the world have their FRT standards. Ref. (1) collects, compares, and examines many FRT standards, and becomes quite helpful. At present, most utilities of developed countries already have or are now preparing FRT standards, which are shown in Fig. 9.28. Of course, RE must not stop at condition of upper side of line in the figure.

Three levels of voltage-sag depths to be endured by FRT, that is, 0%, 15%, or 20% residual voltage. In the figure, the deepest voltage sag measured by the author is also shown. Residual voltage is around 15%, and FRT standards in many utilities seem adequate. Among them, some FRT standards require REs to endure 0% residual voltage. The author thinks that it is over quality. Such deep voltage sag appears by 3 phase-to-ground faults in local network only. Such voltage sag does not spread widely. Although some REs may drop, the amount must be small, and stabilities are hardly threatened. On the contrary, faults on trunk system may threaten stabilities, but such deep voltage sag never appears at load bus.

Duration time of voltage sag to be endured is different by countries or utilities. In the figure, very slow voltage recovery simulated by the author is also shown. By standard of US, RE can endure such slow voltage recovery. If RE cannot endure, voltage recovery must become impossible. Standards of countries and utilities in Europe seem to be somewhat optimistic.

Present REs easily stop due to shallow voltage sag with 20% depth (80% residual voltage). As stated in chapter 4, 5, and 6, the tendency makes system stability ill. The author found that induction motors that consume 50% or more of total electricity supply slow down during voltage sag, and as the result, make system stabilities ill. REs drop by voltage sag make the ill stability more ill. The results are published in some papers. The phenomena never appear in simulation if IMs are not modeled. The other engineers say that RE drop due to voltage sag may result large power flow in interconnection, and oscillatory stability is threatened. The phenomenon appears if IMs are not modeled. But, it is not published as papers. It is not clear what affects, FRT standard is going to be adopted in RE integration rule in the next revision.

Standard to be adopted is to continue operation even if residual voltage is 30%. 20% residual voltage is regarded difficult by present technologies in phase measuring. It is fault accompanying wide area voltage sag, that is, fault on trunk system that FRT should show its excellence. The author has made it sure that 30% or less residual voltage hardly appears by such faults using several hundred measured data. Certainly the lowest measured residual voltage is 10% or so, but the fault occurred on 66kV local network and voltage sag spread in only narrow area. Even if all REs in the narrow area drop, no system stability problems occur.

In other words, FRT performance of 30% residual voltage that can be realized by present technologies is sufficient from viewpoint of system stabilities. In return, all REs have to be ruled to have FRT capability. FRT with 30% residual voltage is easily realized and was already realized in some converter by researches of the author.

However, wind power must be paid some attention. Inverter-interconnecting type is similar to PV and has no problems. Most large wind power connects HV network and anti-islanding function is useless. If needed, DVS function is easily realized. But DFIG (Doubly Fed Induction Generator) type seems difficult to realize FRT function presently. No example of FRT type wind power appears in market until 2011. How DFIG wind power manufacturers do if FRT is required in revised integration rule.

FRT function with lower residual voltage is going to develop in future. But, the author recognizes as a better practice, and is not a strict target even if sacrificing something. On the contrary, to abandon all FRT due to some difficulty is an extreme random remark.

Measures for Frequency Stability Problems

[Battery Speed Governor] By analyses in chapter 7, there are two causes that RE spoils frequency stability of islanded hydro power system. The first is anti-islanding method using negative frequency sensitivity. It can be forbidden, because the other active ant-islanding methods exist. The second is that DVS function on RE spoil frequency stabilizing effect of Δf type PSS. It seems a little serious. However, some battery will be introduced for the other issues such as fluctuation smoothing. If the battery has speed governor function, it must be good control with very small delay. Here, the delay is assumed as 1 sec on 1st order low pass filter. Such performance is easily realized.

Frequency response of total speed governing system that is consists of 70% of quite unstable hydro speed governing system with up to 2 sec T_w of large water hammering effect and 30% of battery speed governing system with 1 sec delay low pass filter is calculated as Fig. 9.40. Phase delay is dramatically reduced. Frequency instability cannot be imagined. The issue is locating possibility of battery in area of islanded hydro power system.

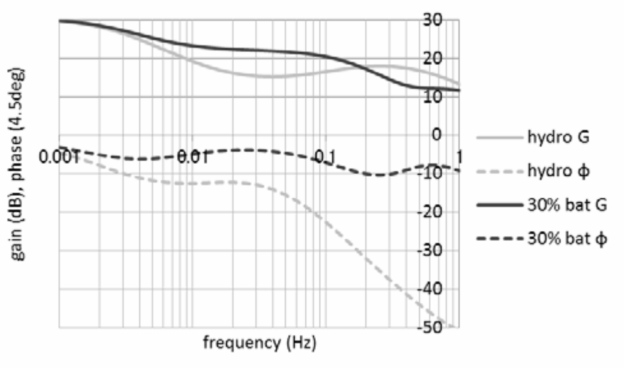

Fig. 9.40 Effect of 30% mixed battery speed governing sys.

[Temporary Blackout of Islanded Hydro Power System] As stated in chapter 7, frequency instability is a phenomenon unique in islanded hydro power system. Utility employing the author has high share of hydro power, and has a doctrine that islanded hydro system is maintained and re-parallel to main system in a short time. However, possibility of islanded hydro system with 1GW load is rare, and another doctrine that islanded hydro system is once go to blackout and restore by sending power to outage loads rapidly from main system is dominant.

In Japan, size of network equipment is larger, and loads in once outage islanded hydro system can be fed from main system without assistance by once shut down hydro power. Therefore, even if islanded hydro system once goes to blackout, time for restoring loads is very short, and as the result, motive for maintaining islanded hydro system is not strong. By cool thinking, it is not definitely important to consider frequency instability that is limited in islanded hydro power system seriously.

Measures for Voltage Deviation Problems

Although minute simulations are needed for obtaining results, the author roughly presumes that voltage deviation can be avoided by combination of vector LDC on distribution transformer tap, that on SVR, and PV's Q = -0.2P leading power factor operation, even if any PV penetration at 53GW level in Japan come true. These three are already verified matured methods, most simple distributed on-site control, additional hardware are only SVR, PT and CT for LDC, therefore, very economical. Cost of “smart grid” methods based on two-way communication is not estimated yet, but must be much higher than the three methods above. Two way communication enables demand side control. But is its value so high when even nuclear curtailment becomes a method?

By the way, the author deduced that there are two types of LDC; “vector LDC” and “scalar LDC”, and the deduction was found to be true by hearing, and is was also found that two utilities use vector LDC, four use scalar LDC, and four use scheduling. As PV penetrates, distribution voltage rise becomes serious problem if only PV’s leading power factor operation is adopted and vector LDC is not adopted. Scalar LDC causes negative effect on LDC in bank reverse power flow. It is not “noblesse oblige” way that small residential PV is required uneconomical measures while large power system is not required today’s best practice, that is, vector LDC. Fortunately, since there is considerable time until PV’s high penetration, utilities should learn and equip vector LDC. Now is the starting point.

In the background of the fact that such a mutant as “scalar LDC” appeared lies an approximately true but strictly wrong recognition that “When load current is large, voltage drop is also large, therefore, substation voltage should be increased.” Strictly true recognition is that “LDC presumes load’s weighted average voltage and regulates it to scheduled value.” Engineers must reflect on the fact that wrong words created a mutant.

Smart Grid

Definition of the words is not clear, but the words certainly has the meaning that intends positive effect by combining REs such as wind and solar and demand equipments such as heat pump and EV with power system using two way communication. In Japan smart grid (SG) is very often referred especially hoping to solve power system impacts due to high RE penetration. On the contrary, problems of SG are rarely referred except such crimes as communication or privacy invasion.

Are there no other problems really? As a hint, SG is sometimes expressed like a human body as a metaphor as Fig. 9.43.

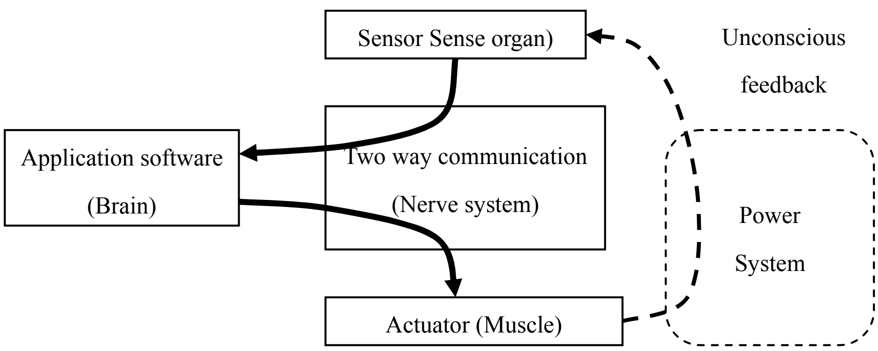

Fig. 9.43 Structure of smart grid as a metaphor of human body

[Problem 1] and [Problem 2] are derived from the figure immediately.

[Problem 1] It is added part by dashed line in the figure. If actuator moves, power system certainly somewhat affected. It is quite possible that the result is detected by sensor. Then, the unconscious feedback loop is formed. By the way, some time delay is needed for work by two way communication and application software. Much time delay is needed for high level work. Much time delay exists in feedback loop. Such loop becomes very unstable, which means not only that work becomes impossible but also that control result cannot be forecasted. When SG is realized, stable feedback loop with large time delay is also realized.

[Problem 2] Technologies of sensor, two way communication, and actuator are nearly completed. However, application software (brain) is not built. Number of the objects that the brain deals is tremendously large. Perhaps, the brain will be highly sophisticated artificial intelligence (AI) having learning ability. It is true that many engineers in SG field once worked in AI field in the past. Terminals also become smart and will be a kind of sensor actuator complex. When SG is realized, it can be said that human at first create complex large artificial intelligence.

[Problem 3] Another problem exists though unconscious from the figure. SG is sometimes called as "the second internet". The reason that internet succeeded is very roughly saying that what exists beyond terminal is human. Human has common sense, do correct decision, and bears responsibility. However when SG is used in power system control, what exists beyond terminal is mare machine. By gigantic number of combination, to examine all functions of SG is impossible. If disaster occurs, who takes the responsibility? When SG is realized, problems on resultant responsibility reversion are solved.

The author also certainly feels excitation to join a human great challenge as SG. However, what were proposed till today were no more than sales of auxiliary equipments except brain. In is also too risky to wholly depend on an uncompleted technology such as SG, even if hope to SG is extremely high. Intermediate solution that half of problems are solved by SG technology can exists. To reduce burden on SG technology, and as safety net, problems by high RE penetration must be solved as many as possible by economic and reliable methods.

System Engineering

It may be surplus for readers but the author intends to a little minutely introduce. In "system engineering" that the author learned in university teaches that three types of solution must be prepared. The three kinds are as follows.

[Solution A] Aggressive "solution A" is advanced, sometimes adopts unrealized technology, and hardly become old-fashioned. Therefore, life as system is long and life time cost is low. However, it may not be completed by time limit.

[Solution B] Balance oriented "solution B". Intermediate between A and C.

[Solution C] Conservative "solution C". It consists of only now available technologies, is surely completed by time limit, but soon become old-fashioned and life time cost may be high. It must be prepared for the case that all ambitious trials are found to be failures. In addition, it is the base for evaluating more aggressive solutions.

SG is certainly an aggressive "solution A". System impact mitigation measures introduced in the book are perhaps conservative "solution C". System engineering teaches that both "solution A" and "solution C" are important and indispensable. Between them, numerous "solution Bs" can exist. To decide what solution is the best, it is helpful to employ the four indices; Usefulness, Economy, Reliability and Compatibility, so system engineering teaches.

Among the indices, Compatibility is unfamiliar word and needs some explanation. Any system starts as a part of supersystem. If the system stands alone in supersystem, the system is said to not have compatibility. If the system is welcomed by supersystem, the system is said to have compatibility. Typical example with rich usefulness and poor compatibility is the Shinkansen. Relationship with supersystem is sometimes called as "Backward Compatibility".

As the dual concept, "Forward Compatibility" exists. If the system extends to future but never limited, new system is needless. Such system has long historical life and economical in long term, and called as extendable. Typical example is parallel connected alternate current (AC) electric power system designed by Tesla. When electric power was first realized, series connected direct current (DC) power system was used by Edison. Parallel connection can be more easily extended than series connection. Alternate current is more useful than direct current. Thus, after Tesla, AC power system is showing very long life even in today.

How do the readers feel? System engineering is useful, isn't it? However, it has a flaw. Much kind of parts are included in a system. Knowledge on such parts is needed. To obtain such knowledge, long training period is needed. Even doctor course is not sufficient at all. Fruits cannot be harvested in a short period. Naturally such field is kept respectful distance by engineers. If no one cares the situation, such an important knowledge will be lost. So, electric power utilities and electric equipment venders collaborated to build up so called "Power Academy", and started co-working with universities in electric power system, system engineering, and the other electric power engineering fields. Such activity will be quite necessary and it is also one of corporate social responsibilities.

References

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