9. Anti-Islanding of RE

Today's Status of RE's Anti-Islanding

When RE output and demand are balanced, an islanded system can be created. If a failure is included in the islanded system, especially if the failure results human injury, the islanded system must be shut down as soon as possible. This is the radical need for anti-islanding, which is classified into two types as follows.

[Collaboration of System and RE] The first is methods by collaboration of power system and RE. Detection of islanding is done at system side, because it is easier than at RE side, and information of islanding is sent to RE, which shuts down itself. It is quite reasonable and seems to have high reliability. Major three methods that have been developed and tested around the world are introduced as follows.

Remote Shutdown Power system recognizes islanding possibility by circuit breaker tripping, sends information to RE. RE can shut down by the information. A utility in Japan is earnest in development of the technique.

Permissive Signal Transmission Signal that permit RE to interconnect may is sent by power line communication. By tripping circuit breaker, the permissive signal also stops. RE can recognize islanded status and can shut down itself.

Forced Grounding and Short Circuit Just after tripping of circuit breaker, islanded feeder is grounded and short circuited at the feeder side terminal of circuit breaker in substation. Protection devices on RE are hoped operate, each RE and the islanded system are hoped to be shut down.

Investment price in case of "forced grounding and short circuit" is estimated as follows. Peak demand of Japan is around 180GW. Peak demand of a distribution feeder is assumed as 3.6MW. Then number of feeders, which is equal to number of circuit breaker to be improved, is calculated as follows.

180GW / 3.6MW = 50000

Additional cost for the improvement is assumed 1M¥ a breaker. Then, total cost is calculated as follows.

50000 * 1M¥ = 50G¥

The amount is further less than cost of "storage battery". In addition, all circuit breakers are not necessarily replaced simultaneously. Replacement can be performed one by one according to needs. Removed circuit breakers can be reused if they are still sound. In 20 years all circuit breakers now operating will reach their life end, and all circuit breakers will become already new type.

In developed countries except Japan, anti-islanding is not taken into Grid Code yet, however, seems to be taking into Grid Code, because the first methods with high reliability have been developed and field tests have been made. Considering the publication date, "Forced Grounding and Short Circuit" seems to be regarded as the most promising [(1)(2)].

[Anti-Islanding by only RE Side] The second is methods by only RE side. It is not so easy to detect islanded status. Therefore, the second methods seem to have poor reliability. As the result, it is only Japan that regards the second methods as the major scheme. The second methods are classified into two types as follows.

Passive Methods The methods try to detect islanded status using values and time-variations of physical variable measured at RE terminal. The methods do not detect islanding itself but detect abnormal status of power system including islanding instead. Therefore, the methods have a serious problem of mal-detection from the beginning. Especially, “phase jump detection” method that was favored because of its high sensitivity has become to be noticed as a method with the most frequent mal-detection, which spoils FRT function at the instance of most needed when FRT should support system stability.

Active Methods The methods adopt signals injected from RE to system also as measured variable for islanding detection, and are hoped as more reliable at the beginning. However, it was proved that signals from multiple REs cancel each other, and performance was reduced.

Thus in Japan, the second methods have been taken into the standard, even then they were known to have poor reliability and poor compatibility. The author guesses the reason as follows. (This is no more than a guess and has no evidence.) At early stage of RE penetration, electric power industry intended to obstruct RE’s high penetration. As a powerful weapon, anti-islanding by RE side only was introduced.

In addition, a guess as follows is also possible. Among the first methods by collaboration of system and RE, forced grounding and short circuit is needed only in systems where anti-islanding is indispensable, and only at the time when RE penetration reaches to the revel that needs anti-islanding. On the contrary, the other methods claim RE to provide anti-islanding function from the beginning. This means an advanced cost payment.

From the first stage of RE penetration, the subject of establishing Grid Code was utilities’ distribution section, which historically had deep connection with sales section. It is no wonder that distribution section has stood against RE.

Frequency Feedback Method with Step Injection

Thus, RE had been burdened a heavy duty. However, a wonderful active second method was invented. That is “Slip Mode Frequency Shift Method”, which has evolved to have additional function of step injection that will reduce detection delay. The evolved method was named “Frequency Feedback Method with Step Injection”, and believed as the ultimate anti-islanding method in Japan. However in general, to understand anti-islanding seems to be difficult, and queer explanation is made on the method. Therefore, the author will correct.

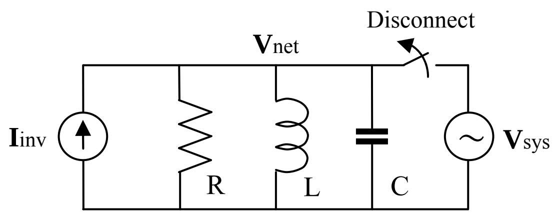


Fig. 9.1 Islanding of inverter power source

Structure shown in Fig. 9.1 is assumed. Inverter power source can be regarded as current source $\mathbf{I}_{inv}$. Load can be regarded as parallel composite of resistor R, reactor L, and capacitor C. Power system can be regarded as voltage source $\mathbf{V}_{sys}$. It is supposed that inverter generation and load are just well balanced and are disconnected from power system. The method controls IGBT gate so that phase of inverter current I_{inv} leads phase of network voltage $\mathbf{V}_{net}$ by $\Delta\phi_{Iinv}$ when frequency of network voltage $\mathbf{V}_{net}$ exceeds rated frequency by Δf_{Vnet}.

If frequency rises, capacitor becomes dominant in load, and load current phase slightly leads. On the contrary, if frequency decreases, reactor becomes dominant in load, and load current phase slightly lags. As the results, load current shows such characteristics as shown in Fig. 9.2. Inverter intends to leads inverter current phase to network voltage phase, when frequency of network voltage rises. However in case of islanding, network voltage phase also rise as inverter current phase. Therefore, inverter must lead inverter current phase more and more, and as the result, frequency of network voltage rises and becomes stable at point C in the figure. On the contrary when frequency decreases, point A is stable equilibrium. Points A and C are stable equilibriums but B is unstable equilibrium. If operational point very slightly deviates from point B, it must go to point A or C. Thus, inverter operational frequency deviates from rated frequency, and islanding can be detected. Of course if interconnected, network voltage phase never changes by inverter current phase.

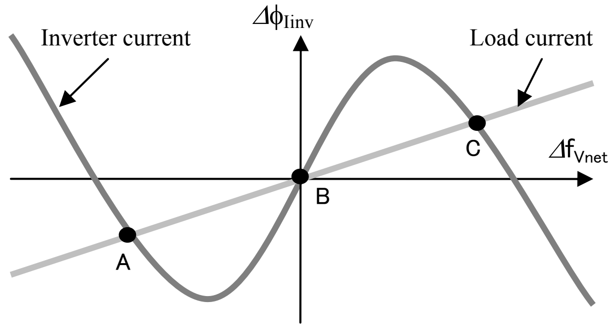


Fig. 9.2 Principle of slip mode frequency shift method

Explanation above is based on original Ref. (3) with some words as supplement. Since the original correctly describes, perhaps readers will understand. On the contrary, Ref. (4) wrongly describes as follows. Do readers understand well? … "In case that total power factor of load combined with resistor is lagging, just after switch-off (islanding), inverter intends to maintain current phase up to now and operate so as to lead voltage phase."… Inverter never has function to lead voltage phase. If voltage phase leading appears as result of something, the cause and the way to the result must be described.

Besides explanation problems, it is attractive that islanding detection can be successfully done when many inverters with the method are included in an islanded system. However, it is slightly troublesome that islanding detection will take a long time if active and reactive powers of the islanded system are quite well balanced. For a solution, Ref. (4) proposes a method. Step change in inverter current phase is made when anything indicating possibility of islanding is detected. By the step change, islanding detection time can be sufficiently reduced, so Ref. (4) reports its simulation and experiment results.

The method is recommended as "new active method" in Ref. (5), but its explanation is written as follows. Do readers understand well? … "The method detects islanding fast by sudden reactive power injection so as to enlarge frequency deviation from ramp rate of power system frequency deviation." … In islanded condition, what exists outside of inverter is only load. It is physically impossible to inject reactive power without changing inverter's voltage or frequency. In the explanation, reactive power injection is regarded as cause, and frequency change is regarded as result. Verification of such causality will be quite difficult.

Besides explanation problems, the method seems to be promising. Ref. (4) has verified by experiment that the method is still effective if induction motors are included in the load. In addition, Ref. (6) reported that the method is still effective even if synchronous machines having comparable capacity as RE are connected to the islanded system. Passive methods with frequent mal-operation will be not used for direct tripping but used as trigger for step injection.

Impact onto Power System Stability

Thus at a glance, anti-islanding by only RE side seems to become perfect. But, is it true? Because, active anti-islanding methods intend to make small islanded system (consists of RE and load) unstable. If so, as the result, they may also make large interconnection (consists of RE, load, and synchronous generator) unstable. The instability will begin from small step injection, and deviation will grow. That is closed loop instability. Therefore, oscillatory stability will be most anxious. Therefore, reality of the anxiety is examined hereafter using simulation.

[Power System Model]

Since analysis and simulation results of power system stability significantly depends of power system model design, to use an authorized model that is adequately aggregated existing power system is favorable. However, there is no authorized model that adopts motor load or adequate aggregation method. Although the authors have built an adequate one, it is quite difficult to introduce the model in space of usual paper. Therefore, as second best, 1 machine, 1 load, and infinite bus model that is built by aggregating existing power system so that it can be described in space of usual paper. The authors hope that today's authorized power system model is improved adequately.

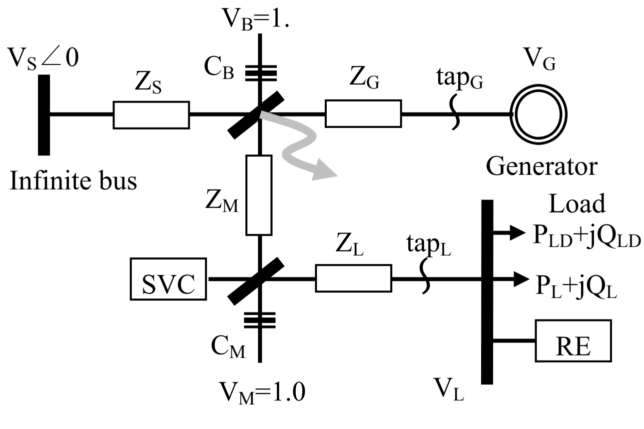


Fig. 9.3 Structure of the studied system

1 machine, 1 load, and infinite bus model used here is built by aggregating some part of existing power system with poor stability in Japan. Since it has been reported that unstable phenomena are different in power sending system (generation > demand) and power receiving system (generation < demand) in foregoing researches by the authors [7][8][9], both power sending and receiving systems are introduced here. Common structure of those systems is shown in Fig.9.3, and network impedance and power flow condition are shown in Table 9.1 (machine capacity base p.u. value with no RE). At a glance, Z_S is very large. It means loose interconnection. Since weight of tie-line impedance is not dominant in Z_S, it is not effective to

reinforce tie-line only to improve power system stability. C_B means capacitance of EHV cable in metropolitan, and C_M means a lot of capacitor at 66kV class midway bus. At the two capacitors voltage is set as 1.0, and values of C_B and C_M are decided as the result of power flow calculation.

Table 9.1 Network impedance and power flow

	Z_S	Z_G	tap_G	cap. gen
Sen	0.0896+j3.2302	0.0063+j0.2058	0.97	1.0000
(RE)	0.0896+j3.2302	0.0063+j0.2636	0.97	0.7220
Rec	0.0283+j1.3167	0.0153+j0.2812	0.97	1.0000
(RE)	0.0283+j1.3167	0.0153+j0.4158	0.97	0.5271
	Z_M	Z_L	tap_L	
Sen	0.0040+j0.3591	0.0099+j0.2701	1.05	
(RE)	0.0040+j0.3591	0.0099+j0.2701	1.05	
Rec	0.0014+j0.1125	0.0018+j0.1204	1.05	
(RE)	0.0014+j0.1125	0.0018+j0.1204	1.05	
	P_G	P_L+jQ_L	$P_{RE}+jQ_{RE}$	
Sen	0.7601	0.6885+j0.06865	0	
(RE)	0.5488	0.6885+j0.06885	0.2060-j0.04120	
Rec	0.8274	1.2706+j0.12706	0	
(RE)	0.4361	1.2706+j0.12706	0.3812-j0.07624	

A typical thermal generator is adopted as the one machine in the model. It must be noticed that two damper winding should be modeled on Q axis in case of cylindrical rotor [10]. Since the rotor is an iron lump, current goes not only rotor surface producing damping torque but also in larger loop like field winding on D axis without producing damping torque. Therefore, double Q-axis damper winding machine model necessarily shows poorer oscillatory stability than single Q-axis damper winding machine model, which bring false good stability.

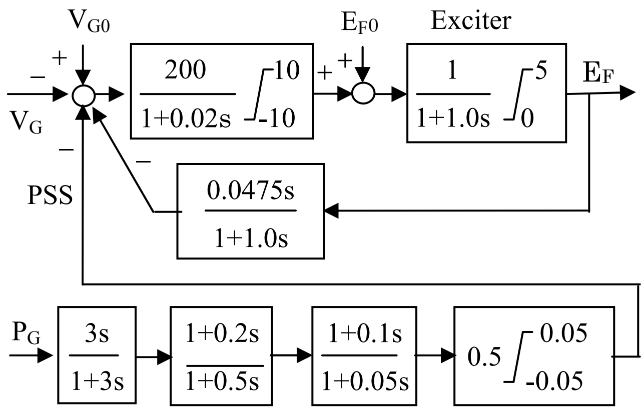


Fig. 9.4 Exciter-type excitation system with PSS

Power system stability also much depend on excitation system design. Here, a typical exciter-type with PSS shown in Fig. 9.4 is adopted.

Peak demand is assumed. Lad demands 50% reactive power of its active power and 40% amount of capacitor compensate the demand. As the result load reactive demand with capacitor is 10% of its active power. For simple partial load drop due to voltage sag is ignored. Load is modeled as mixture of 50% induction motor and 50% constant impedance. It has been proved that 50% of electric energy is used in motor through analysis of voltage sag record by the authors (11) and load survey by government and private investigations (12). It has been also proved that unit inertia constant of motor is 0.5 second and motor loading (input kW / capacity kVA) is 50% by analysis of the authors, and those parameters are adopted. Motor's machine constants were already investigated and prepared in simulation tool by CRIEPI, therefore, those data are used.

Here integrated Photovoltaic (PV) as RE by 30% of load demand. As RE is very often called as Distributed Generation (DG), its size is small and it scatters in lower voltage network nearby load. Here, PV is connected at load terminal. Since peak demand of Japan is 180GW, integrated PV capacity is 54GW, which is very close to integration target of Japan government in 2030 (53GW). FRT (Fault Ride-Through) design is assumed in PV. Therefore PV never stops due to voltage sag. PV is operating at its rated output and at Q = -0.2P constant leading power factor. Output of generator is decreased by PV's output and capacity of generator and transformer (whose impedance is j15% at generator capacity base) is decreased proportionally. Network impedance and power flow condition turn to (RE) lines in Table 1. Although PV operates at its possible maximum output by MPPT, it cannot follow fast power swing. Therefore, PV is assumed to operate in constant current (both active and reactive power) by ACR. It was already reported that stability error due to representing RE as negative load is negligibly small (13).

As anti-islanding, newly developed "Frequency Feedback with Step Injection" is adopted. Since step injection is not large and its trigger condition is not clear, frequency feedback only id modeled here as follows. Parallel with PV, a high impedance synchronous machine (synchronous reactance 400%, leakage reactance 320%) is set, and its reactive power is regulated by excitation system as shown in Fig.3 to reference value that was calculated from frequency deviation. Sensitivity is sea as -30 p.u., which is equal to 50%MVar/Hz (1Hz frequency deviation brings 50% reactive power change of its machine capacity). The reason why high impedance synchronous machine is chosen is to avoid unnecessary stability improvement by providing reactive power during low voltage period. Since PV active power is provided by the synchronous machine with high impedance will bring ill transient stability, active power and its -20% reactive power is supplied by negative constant current load.

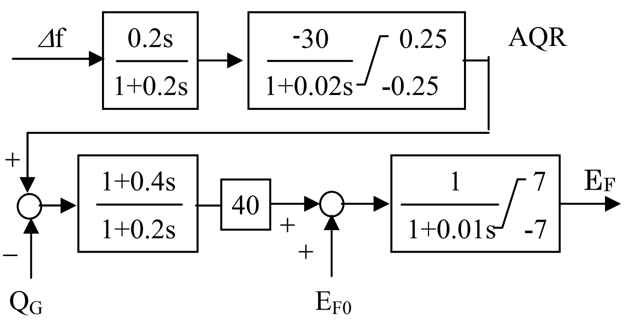


Fig.9.5 Excitation system for anti-islanding

Fault is assumed at gathering point of system branch (Z_S), generator branch (Z_G), and load branch (Z_M) as Fig. 9.3. In case of assessing oscillatory stability, which is also called as small signal stability, excessive contingency must be avoided and three-line-to-ground fault clear via a large fault impedance (Z_F = j5.0p.u.) is adopted and cleared after 0.07 second. In case of assessing transient and short term voltage stability three-line-to-ground fault via a small fault impedance (Z_F = j0.3p.u.) is modeled instead.

For a countermeasure that improves power system stability, SVC is prepared and its amount is expresses by ratio to RE capacity. Although SVC will be most effective when located at load bus, SVC and RE's anti-islanding will interfere each other. Therefore, SVC is located at 66kV class midway bus (V_M). SVC output Q_{SVC} by voltage V is assumed as follows. 60% reactive power of SVC capacity is supplied in case of sufficient low voltage period.

$$Q_{SVC} = 4 \left[(V/V_0)^2 - (V/V_0)^3 \right]$$

[Impact by Anti-Islanding RC] Since a certain impact by RC representation of anti-islanding function can exist in, the impact is assessed at first. Growth or decay of power swing with RC or without RC as affected by tie-line power flow is shown in Fig. 9.6 (Sending System) and Fig. 9.7 (Receiving System). Difference by RC is very small as intention of the author.

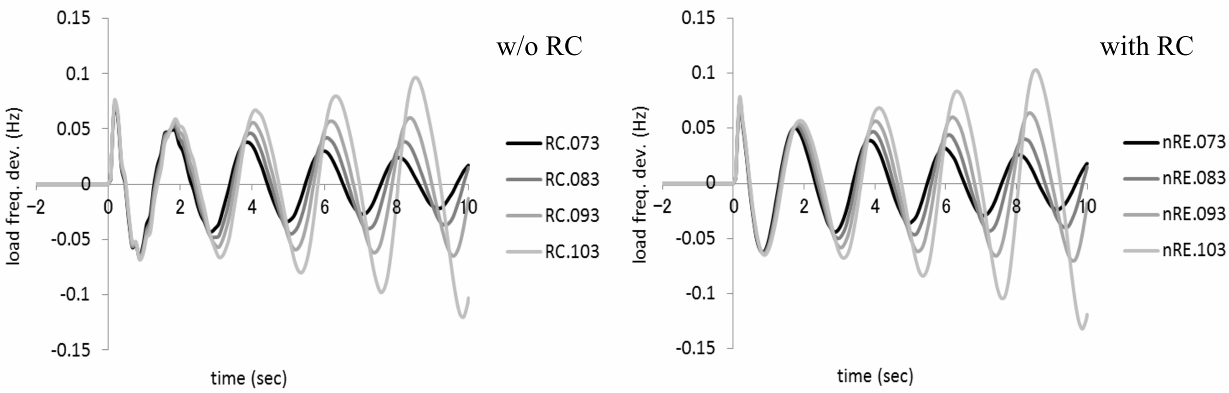


Fig. 9.6 Growth or decay of power swing by tie-line power flow (sending system)

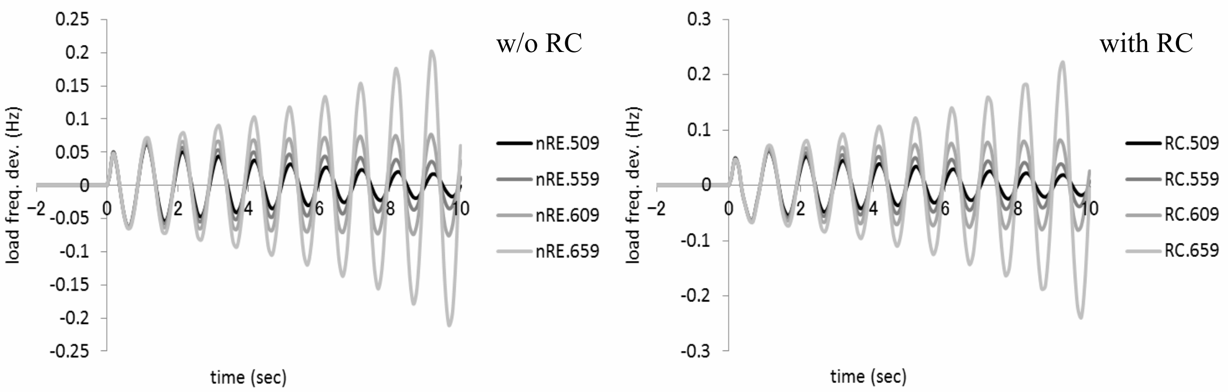


Fig. 9.7 Growth or decay of power swing by tie-line power flow (receiving system)

To assess impact by the RC, growth/decay speed of power swing envelope is approximated by exponential curve. The results are shown in Fig. 9.8 (sending system) and Fig. 9.9 (receiving system). The exponential curve represent growth/decay speed of power swing envelope, and the growth/decay speed as affected by tie-line power flow is calculated as Fig. 9.10. The tie-line power flow that makes growth/decay speed zero means the stability limit. The limit tie-line power flow is 0.0885 (w/o RC) and 0.0901 (with RC) in sending system, and is -0.5947 (w/o RC) and -0.5924 (with RC) in receiving system. Difference due to RC is so small as around calculation error, and assessed as practically negligible.

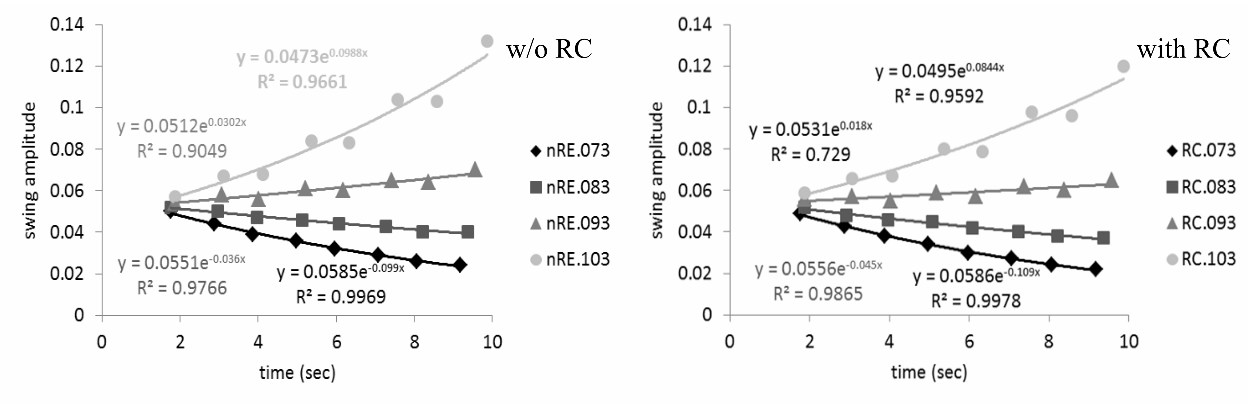


Fig. 9.8 Growth/decay of power swing envelope as affected by tie-line power flow (sending system)

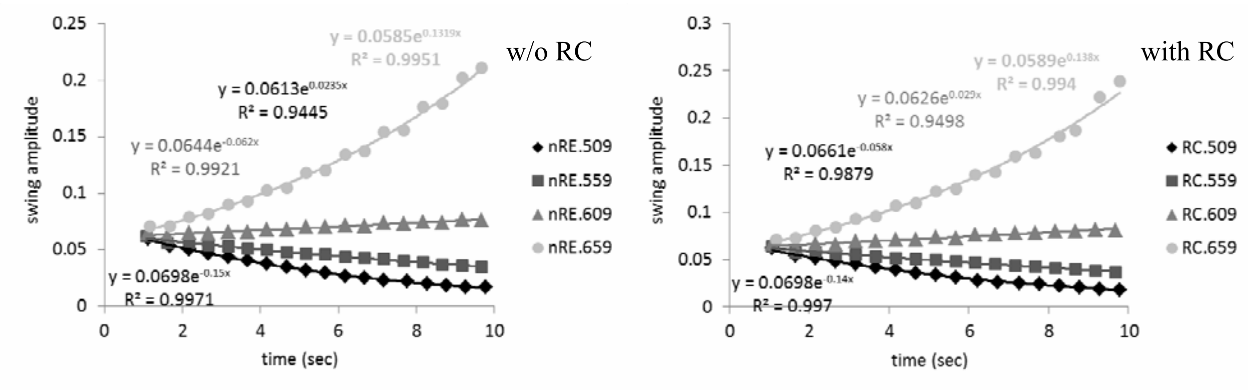


Fig. 9.9 Growth/decay of power swing envelope as affected by tie-line power flow (receiving system)

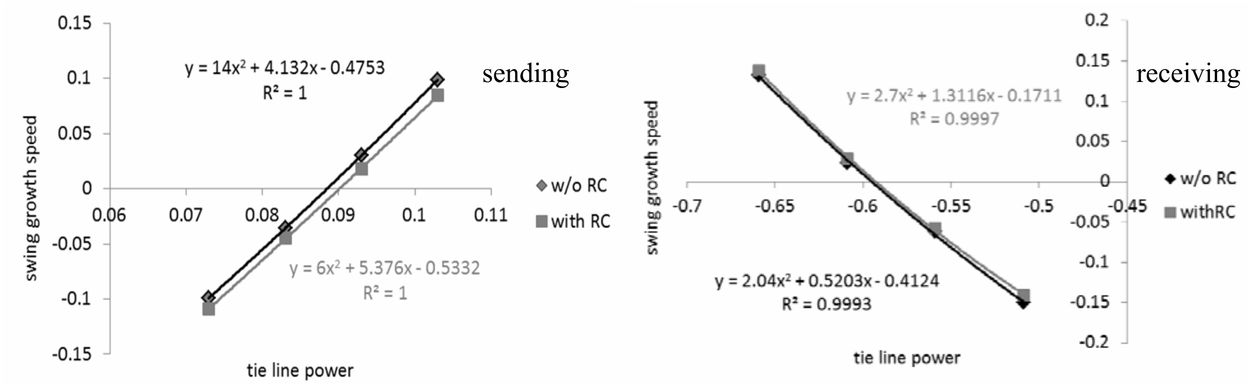


Fig. 9.10 Growth/decay speed of power swing envelope as affected by tie-line power flow

[Power Sending System]

Oscillatory Stability in Power Sending System At first in case of oscillatory stability assessment with Z_F = j5.0, by increasing tie-line sending power, the tie-line power (Ps) resulting durable power swing is found by interpolation about the five cases as follows, and the results are compared in Fig. 9.11.

A. no-RE: before RE integration.

B. RE: after RE integration, but anti-islanding is unused.

C. ISL: anti-islanding is used.

D. SVC: SVC is used in case C.

E. Ex: fast response excitation system is adopted in case C.

The reason why oscillatory stability is improved by RE integration is that loose interconnection spoiling stability is mitigated by decreasing generator capacity. Anti-islanding shows no ill effect on oscillatory stability of power sending system. SVC with 10% capacity of RE improves stability. Fast response excitation system also improves stability.

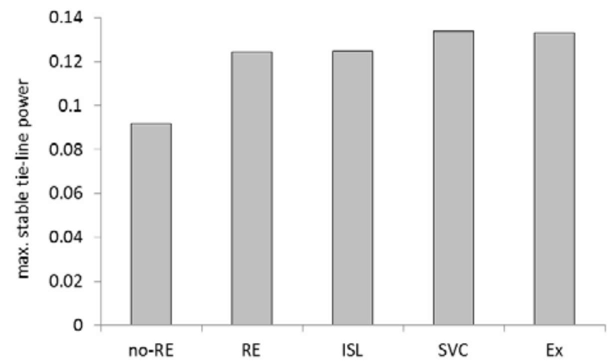


Fig.9.11 Oscillatory stability of power sending system

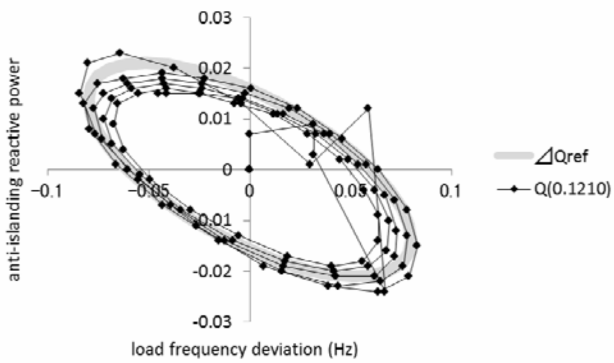


Fig.9.12 Verification of anti-isl. representation (Sen)

Verification result whether the representation of anti-islanding in Fig.9.5 can perform as intended is shown in Fig.9.12. Lissajous must be figured in reactive output of anti-islanding (vertical axis) - frequency deviation (horizontal axis) plane. The figure must almost agree with another Lissajous drawn by the representation (with additional time delay 0.01 second by exciter and synchronous machine 0.02 second). Fig.9.12 shows positive result, and the anti-islanding representation here is verified.

As a simulation result, case C is introduced in Fig.9.13. As tie-line sending power increases, swing becomes slowly fade out, and swing becomes increasing in case of sending power 0.1403.

By the way it is well known by experience that maximum stable tie-line sending power will significantly increase when PSS is set optimally. Simulation result with an idealistic PSS setting that has been the best PSS setting by the author instead of case D is shown in Fig.9.14. Even in case of 0.1596 tie-line sending power, when generator output almost reaches at its rated value, the system is quite stable, and importance of good PSS setting in power sending system is recognized.

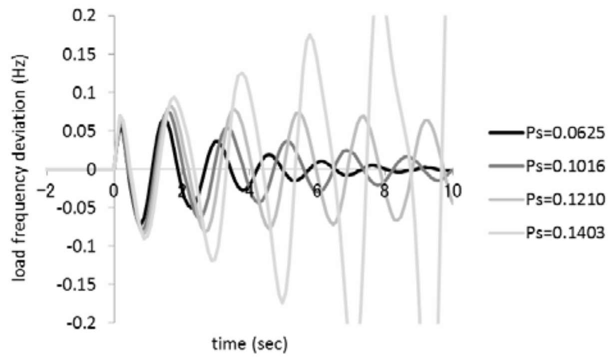


Fig.9.13 Simulation results (ISL case)

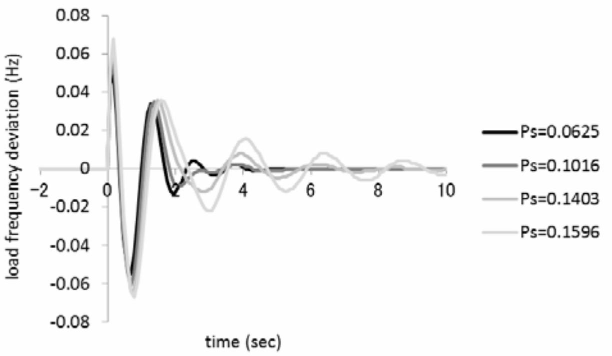


Fig. 9.14 Simulation (ISL, fast Ex, optimal PSS case)

Transient and Voltage Stability in Power Sending System Next, excitation system is fixed as case D so that oscillatory stability is not lost easily, fault impedance is lessened to Z_F = j0.3 and transient and (short term) voltage stabilities are assessed. Increasing tie-line sending power, maximum stable tie-line sending power values in the five cases as follows are compared. The result is shown in Fig.9.15.

A. no-RE: before RE integration.

B. RE: after RE integration, but anti-islanding is unused

C. ISL: anti-islanding is used.

D. Stat: static load model is adopted in case C.

E. Trad: traditional aggregation is adopted in case C.

F. (Osc): oscillatory stability limit for reference.

Certainly stability becomes ill by anti-islanding, but very little. It will be much guilty that stability is wrongly optimistically when either static load model or traditional aggregation is adopted.

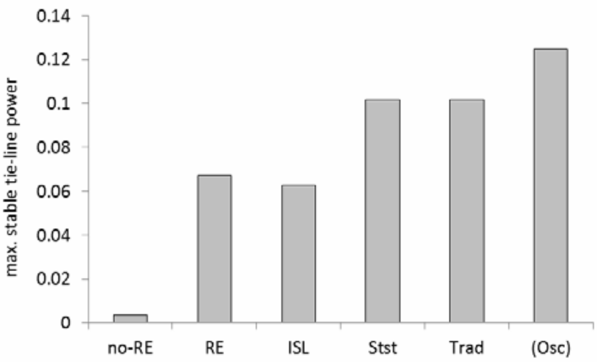


Fig.9.15 Transient and voltage stability (Sen)

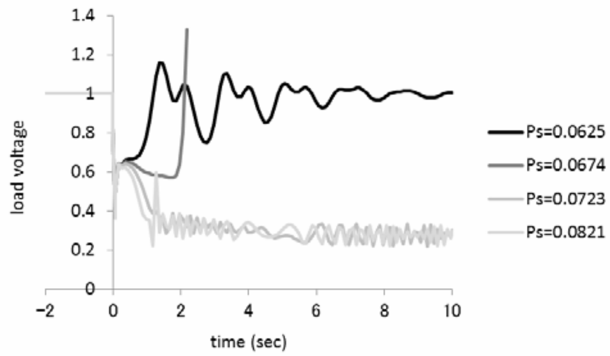


Fig.9.16 Simulation results (ISL, Sen)

As a simulation result, case C is introduced in Fig.9.16. Transient and voltage stabilities are lost at 0.0674 tie-line sending power flow or more. Generator angle is usually adopted for expressing transient stability. However, asynchronism of the generator can be distinguished because load voltage varies very fast. In addition, motor stall can be recognized by low load voltage. Thus, load voltage includes more information than generator angle.

[Power Receiving System]

Oscillatory Stability in Power Receiving System Here also at first fault impedance is set as Z_F = j5.0, and decreasing generator output, critical tie-line receiving power with lasting power swing is found by interpolation about the five cases as follows. The result is shown in Fig.9.17. However in case C, it must be noticed that, generator output must be increase for assessment, and for the purpose, capacity of generator and transformer is increased.

A. no-RE: before RE integration.

B. RE: after RE integration, but anti-islanding is unused.

C. ISL: anti-islanding is used.

D. SVC: SVC is used in case C.

E. Ex: fast response excitation system is adopted in case C.

It is same as power sending system that oscillatory stability is improved by RE integration because loose interconnection condition that spoils stability is mitigated by decrease of generator capacity. However, it is quite different from power sending system that damage of stability by anti-islanding is serious. The spoiled stability can recover with assistance of SVC with 20.6% of RE capacity. Fast response excitation system is also effective in power receiving system [8].

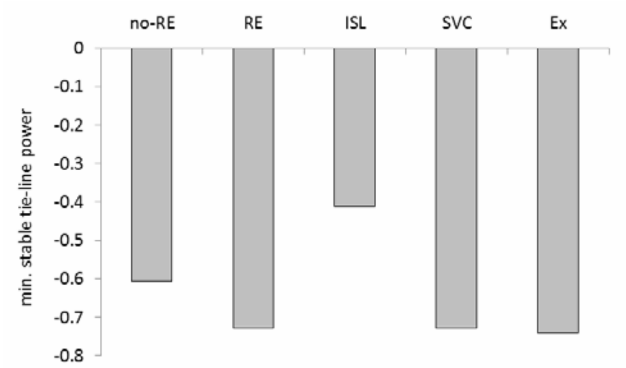


Fig.9.17 Oscillatory stability of power receiving system

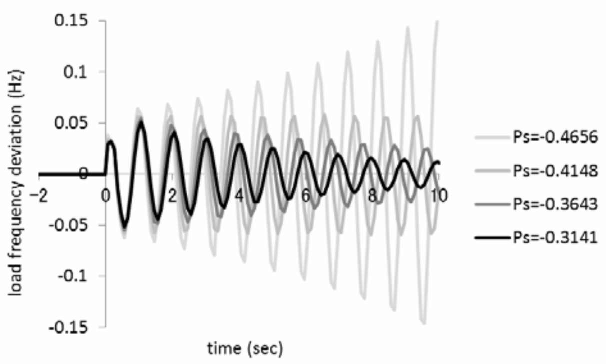


Fig.9.18 Simulation results (ISL case)

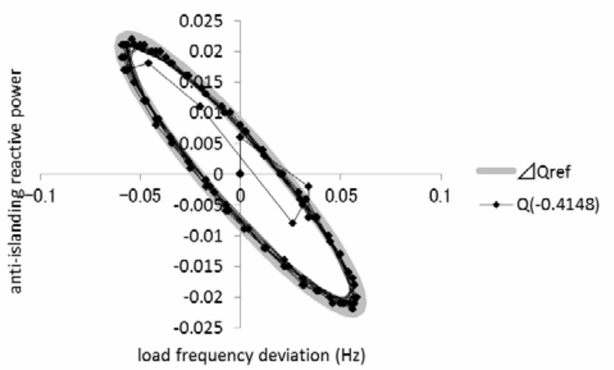


Fig.9.19 Verification of anti-isl. representation (Rec)

As a simulation result, case C is introduced in Fig.9.18. As tie-line receiving power ($-P_S$) increases, swing becomes slowly fade out, and swing becomes increasing in case of receiving power 0.4656.

Reactive power-frequency Lissajous was fat ellipse in power sending system. On the contrary the Lissajous becomes to thin ellipse in power receiving system and becomes close to y = -ax as shown in Fig. 9.19. The reason is that power swing period is quite shorter in power receiving system, and as the result, harmful effect due to anti-islanding tends to appear.

Transient and Voltage Stability of Power Receiving System Next, excitation system is fixed as case D so that oscillatory stability is not lost easily, fault impedance is lessened to Z_F = j0.3 and transient and (short term) voltage stabilities are assessed. Decreasing generator output, maximum stable tie-line receiving power values ($-P_S$) in the five cases as follows are compared. The result is shown in Fig.9.20. However in case of C, generator output must be increase for assessment, and for the purpose, capacity of generator and transformer is increased.

A. no-RE: before RE integration.

B. RE: after RE integration, but anti-islanding is unused

C. ISL: anti-islanding is used.

D. Stat: static load model is adopted in case C.

E. Trad: traditional aggregation is adopted in case C

F. (Osc): oscillatory stability limit for reference

Stability is much spoiled by anti-islanding and it becomes necessary to increase output power of generator, and for the purpose, to increase capacity of generator and transformer. It is also much guilty that stability is wrongly assessed optimistically when either static load model or traditional aggregation is adopted.

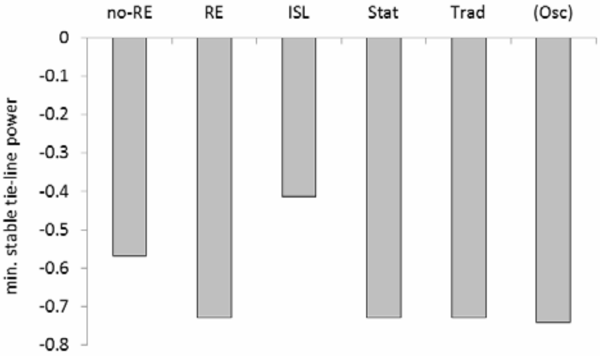


Fig.9.20 Transient/voltage stability (Rec)

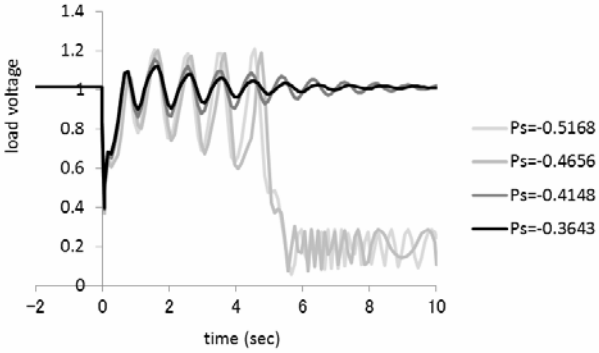


Fig.9.21 Simulation results (ISL, Rec)

As a simulation result, case C is introduced in Fig.9.21. Stability is lost at 0.4656 tie-line sending power flow or more. It can be recognized that generator goes to asynchronism and motor goes to stall.

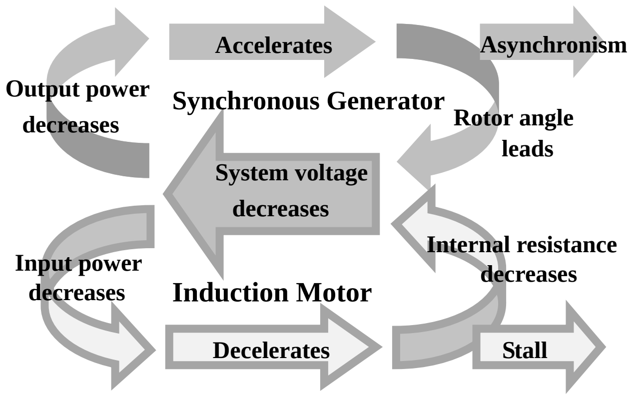


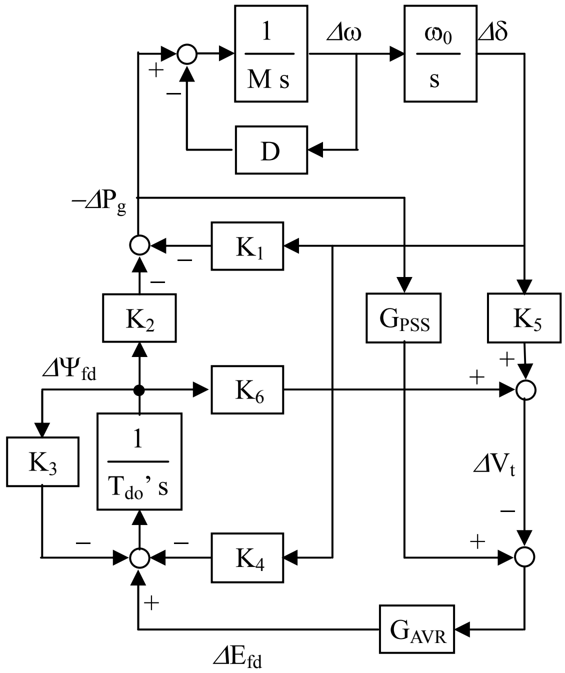
Fig. 5.1(reappear) Mechanism of Asynchronism

Here, transient stability and short term voltage stability are discussed together. The reason is that the two typical rotating machines in power system, that is synchronous generator and induction motor, mutually spoil their stability having system voltage decrease as common factor by the mechanism as shown in Fig.5.1(reappear). Thus, transient stability and short term voltage stability cannot be treated independently any more.

How Anti-Islanding Spoils Stability

By simulation it was found that newly developed anti-islanding function on RE spoils power system stability especially in power receiving system. However, simulation result cannot explain why and how the result is conducted. For researching the mechanism, analysis by engineer by himself is necessary. Unstable phenomena seen here show growing power swing even in case of transient and voltage stability assessment. Therefore, oscillatory stability must be dominant, and large contingency beyond linear operation may bring transient and voltage instability.

Oscillatory stability analysis dad been made by Heffron and Phillips (14), de Mello and Concordia (15), on one machine infinite bus system model, which is adequate when remote generator sends power to power pool, but is not adequate on model that is aggregated existing power system, because the model necessarily has the structure of Fig.1, and therefore, considering power system load becomes indispensable. The request was realized by Komami and Komukai (16), and it was proven that oscillatory instability appears even in power receiving system. Further, Yamagishi and Komami (8) considered distributed generation. Here in addition, anti-islanding on RE is added. All of those research resulted block diagram shown in Fig6.3 (reappear). Load's voltage sensitivity affects to coefficient K_1 to K_6. Nomenclature is as follows.



Nomenclature

P_m: turbine output P_g: generator output
M: unit inertia constant (sec) D: Damping coefficient
ω: speed deviation ω_0: system frequency
δ: generator rotor angle V_t: terminal voltage
G_{AVR}: excitation system gain G_{PSS}: PSS gain
E_{fd}: field voltage Ψ_{fd}: field magnetic flux
T_{do}': open field time constant (sec)
s: Laplace transform

Fig. 6.3 (reappear) Demello's block diagram

Anti-islanding will bring two negative effects as follows. They are positive feedbacks in closed loops, and will bring power swing growth.

[1] frequency rises => anti-islanding absorbs reactive power => load voltage decreases
=> load power consumption decreases => frequency rises (negative load damping)

[2] frequency rises => anti-islanding absorbs reactive power => generator terminal voltage drops
=> excitation voltage rises => magnetic flux increases => generator output increases
=> frequency rises (negative PSS)

[1] can be included into generator's damping coefficient D, and [2] can be included into PSS gain G_{PSS}.

First, calculation result of negative effect by negative PSS is shown in Fig.9.22, in which PSS gain is plotted on complex plane with changing power swing frequency.

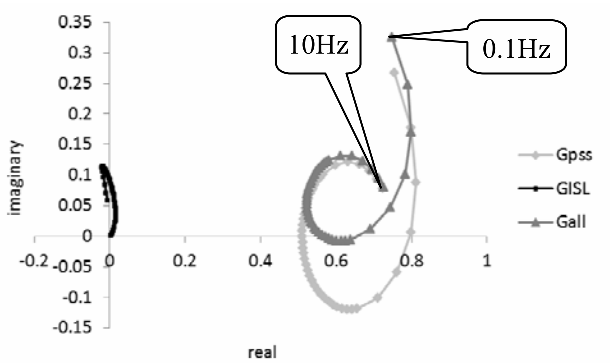


Fig.9.22 Negative PSS effect of anti-islanding

Since PSS gain has a extensive variable ΔP_g as input and intensive variable ΔV_t as output, it becomes inverse proportional to generator capacity, and it is not queer the gain exceeds 0.5 in the figure. Anti-islanding makes PSS phase lead and spoils the effect, but it seems not so fatal.

Second, negative load damping is calculated and the result is shown in Fig.9.23 as total generator's damping coefficient, which is the total of damping coefficients of generator's damper windings, motor load, and anti-islanding. Since large negative damping by anti-islanding is brought by high load active power's voltage sensitivity (transiently 2 and stationary 1), the worse: transient sensitivity case is shown here. It can be seen that anti-islanding spoils damping. In spite of the negative damping, fast response excitation system can recover stability.

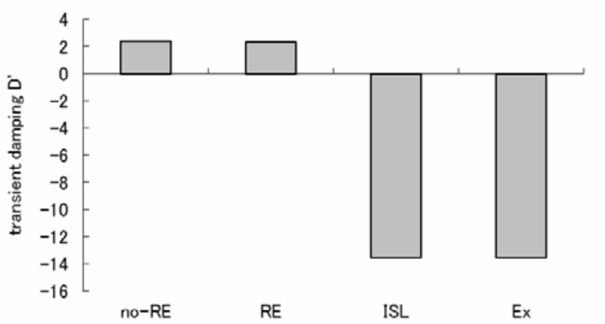


Fig.9.23 Negative damping effect of anti-islanding

For assessing the two negative effects of anti-islanding, it is useful to draw Nyquist's trajectory of open loop gain of Fig.6.3 (reappear) on complex plane as Fig.9.24, in which calculation results in some cases at receiving power flow 0.4656 are shown. If the trajectory goes to zero with looking the point (-1, 0) at left side, the system will be stable. System stability can be approximately assessed by the minimum distance between the trajectory and the point (-1, 0). According to the figure, oscillatory stability is improved by RE integration, is spoiled by anti-islanding, and is recovered by fast response excitation system. The analysis result agrees with simulation result. Therefore, the assumed two factors: negative load damping and negative PSS seem to hit the nail-head.

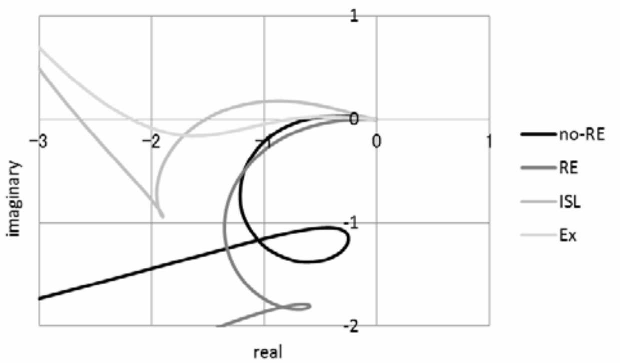


Fig.9.24 Nyquits's trajectories

Remark and Economical Issues

"Frequency Feedback with Step Injection" type anti-islanding is published in RE integration guide line and is hoped as the decisive type. However, minute examination in Ref. (6) has already brought a flaw that sensitivity of the anti-islanding drops when considerable amount of synchronous machines are included in the islanded system to be detected. In addition, the paper introduced that the anti-islanding spoils power system stability especially in power receiving system. The negative effect may hinder or oppose electricity trade and deregulation of electricity industry those are today's social request. Furthermore, the anti-islanding will decrease positive effect with nearby SVC each other. Although at the beginning of development "Frequency Feedback" type seems to certainly consider negative second effects (3), the consideration seems to be lost after development engineers had changed (4). After all, the anti-islanding must be re-examined. In its developing process, opinion of engineers studying islanding only seems to be adopted. Viewpoint of understanding whole impacts of RE onto power system seems not to be considered. This case seems to suggest that governance on technologies and engineers must be reconsidered.

As the countermeasure for the negative effect by the anti-islanding, fast response excitation system is hopeful, and fast-response thyristor type excitation system that has become widely adopted in power system seems to realize the fast response considerably, but a minute investigation will be needed. As additional countermeasure, SVC at such as 66kV class midway bus (remote from RE) seems helpful. Assuming that SVC is needed by 10% of RE capacity (53GW), the cost is calculated as follows.

53GW×0.1×30000 yen/kVA＝159000 million yen

There exist not only anti-islanding made at RE side only but also anti-islanding made as collaboration of power system side and RE side, such as "forced grounding of islanded system" or "interruption of interconnection permissive signal". Assuming that there are 50000 distribution feeders in Japan and the collaboration is realized by 1 million yen per feeder, the cost is calculated as follows.

50000 feeders * 1 million yen/feeder ＝50000 million yen

As conclusion, anti-islanding by only RE side has no insurance of detecting islanded operation surely, and has no economical advantage compared with the other schemes. The authors do not know developed countries that oblige RE to prepare anti-islanding function except Japan. The doctrine that anti-islanding should be made by only RE side must be reconsidered.

References

(1) W. Wang, J. Kilber, G. Zhang, W. Xu, B. Howell, T. Palladino: "A Power Line Signaling Based Scheme for Anti-Islanding Protection of Distributed Generators – Part 2: Field Test Results", IEEE Trans. PWRD, Vol.22, No.3, pp.1767-1772 Jul. 2007

(2) C. Abbey, Y. Brissette, P. Venne: "An Autoground System for Anti-Islanding Protection of Distributed Generation" , IEEE Trans PWRS, Vol.29, No.2, pp.873-880, Mar. 2014

(3) Noro, Shinohara, Kasai, Okado, Sato: "Development of an islanding protection system that operates without interference", IEEJ Workshop RE, PE-10-9, 2010. (in Japanese)

(4) NEDO: Report on "Establishment of islanding detection technology", Aug. 2009. (in Japanese)

(5) The Japan Electric Association: "Grid-Interconnection Code JEAC 9701-2010", 2011. (in Japanese)

(6) S. Uemura, M. Takagi, K. Kawahara: "Preventing Islanding by Distributed Power Generation at Transmission System Fault —Evaluation of Characteristics of Detecting Islanding by Power Conditioning Subsystem for Interconnecting Many Distribured Power Generations in Area with

Rotated Type Distributed Power Generation—, CRIEPI Report, R12020, Jul. 2015. (in Japanese)

(7) T. Ueda, and S. Komami : "Transient Stability Considering Dynamic Load in Bulk Power System with High DG Penetration", IEEJ Trans. PE, Vol. 126, No. 10, pp. 969-976, (2006) (in Japanese)

(8) Y. Yamagishi, and S. Komami: "Power System Dynamic Stability Analysis Considering Dynamic Load and Distributed Generation", IEEJ Trans. PE, Vol. 126, No. 10, pp.977-984 (2006) (in Japanese)

(9) T. Ueda, and S. Komami : "A Study on Decelerating Step Out Phenomenon Considering the Effect of Dynamic Load", IEEJ, The papers of Technical Meeting on PE, IEEJ, PE-05-5, (2005) (in Japanese)

(10) S. Komami : "On the Importance of Power System Model Verification", The Journal of the IEEJ, Vol. 132, No. 12, pp.820-823, (2012) (in Japanese)

(11) K. Mizuo, and S. Komami : "Parameter Identification Improvement of Dynamic Load Model in Power System", IEEJ Trans. PE, Vol. 132, No. 1, pp. 71-76, (2012) (in Japanese)

(12) www.sicalliance.jp/science data/.../fed-power-consume.pdf, (2009) (in Japanese)

(13) T. Tanigawa, N. Kanao and H. Taoka : "A Study of Influence on Power System Stability Analysis of Distribution Generator Models", Annual Conference on PE, IEEJ, No. 146 (2013) (in Japanese)

(14) W. G. Heffron and R. A. Phillips : "Effect of a Modern Amplidyne Voltage Regulator on Under-excited Operation of Large Turbine Generators", AIEE Trans. PE, Vol. 71, Pt. 3, pp. 692-697, (Aug. 1952)

(15) F. P. de Mello and C. Concordia : "Concepts of Synchronous Machines Stability as Affected by Excitation Control", IEEE Trans. PAS-88, Vol. 4, pp.316-329 (1969)

(16) S. Komami, T. Komukai, S. Kimura, and K. Koyanagi : "Effect of Load Characteristics on Dynamic Stability of Power System", IEEJ Trans. PE, Vol. 107, No. 7, pp. 341-348, (1987) (in Japanese)