10. High RE Penetration in Japan

Economical Evaluation of FRT and DVC Functions

Carbon free electricity is an issue in a far future. However 53GW PV penetration target at 2030 by Japan government is realistic. Therefore, it is a responsibility for the generation of the author to build a realistic way for solving various integration issues due to the 53GW PV penetration. In such a situation, proper decision making must be impossible, unless economical effects by PV's FRT and DVC capabilities are quantitatively evaluated. Although FRT claim itself is certainly written in Japan grid code, why FRT is necessary is not clearly written. Since on one hand RE side must burden some cost due to FRT function, on the other power hand system side must burden the responsibility to account why RE's FRT function becomes necessary. Since Japan power system side seems not to finish the account responsibility, the author will do it

The author thinks that there is a reason why FRT function has not been economically evaluated. It is the inadequate power system model in Japan. Standard power system model in Japan employs "Static Load Model" and "Traditional Aggregation". In US, FIDVR (Fault Induced Delayed Voltage Recovery) has already been regarded as a serious problem in 2008, and it has been recognized that considering "Induction Motor Load" that amounts 50% or more electricity demand and considering "Feeder Equivalent" that represents impedance from substation bus to collective load terminal are indispensable for representing FIDVR by simulation. In Japan, two electric demand survey researches (Japan government and private) have reported that 50% or more electricity is consumed induction motor in electric load. In addition, a prior research by the author, which assesses amount of induction motor load from load's dynamic behavior during and after voltage sag incidents, had reported almost same result. In spite of those obvious proofs, power system analysis in Japan has been persistently denying to employ "Induction Motor Load" or "Feeder Equivalent". As the result, a queer model that static loads whose power depends on only present voltage and frequency connect directly to high voltage substation bus. Such a queer model cannot represent FIDVR. However, effect of FRT is best performed in mitigation of FIDVR. A dramatic effect of FRT; unstable situation turns to stable by FRT never appears by simulation using Japan standard power system model. And as the result, inherent economical effect of FRT was not able to be evaluated correctly in Japan, and FRT claim examples of the other countries are only demonstrated.

It becomes indispensable to represent physics of induction motor load and feeder equivalent when economical effect of FRT function is evaluated. Japan 50Hz and 60Hz interconnections must be objectives of analyses. Failure location at which FRT function demonstrates great effect must be sought. In addition, since excitation system on synchronous generator performs an important role in power system stability, characteristics of excitation system, especially frequency response, sealing voltage, and response time must be reserved by weighted average values through power system aggregation. However, such power system models do not exist. Therefore, the author has newly created EAST40 and WEST40 power system models.

Data of the models base on what the author has been collected privately for a long time. Some data are derived from power system maps. Unknown generator data are estimated from similar generators of the same manufacturer and era. Thus, the author intends to keep reality of the models. By employing 40 generators, power system characters only very slightly change through aggregation. However, the models are built by the author privately. They are not concentrated generally. In addition, high reality and high accuracy of the models may bring security problems such as terrorism. Therefore, the author will refrain to publish the models here, but of course, will join and contribute to coming update project of IEEJ standard power system models in the future.

They are assumed that 50% electricity is used in induction motor, that induction motor power (kW) is 50% of its capacity (kVA), and that unit inertia constant of induction motor is 0.5 sec. Load drop ratio ΔP is assumed to be derived from voltage sag depth ΔV by equation as follows.

$$\Delta P = 0.602\,(\Delta V - 0.158) \Big/ {}^{0.25}_{0}$$

Those load characteristics were induced from 467 measured data of load's dynamic behavior during and after voltage sag. Impedance of "Feeder Equivalent" and characteristics of aggregated excitation system were identified by Y-connection aggregation method already introduced in former chapter.

Photovoltaic generation (PV) is assumed as DG, and is assumed to penetrate 28.5% of peak demand by its rated output. The penetration corresponds to 53GW rated output penetration in Japan. Fine climate is assumed, therefore, PV operates at its rated output. For demand supply balance in power system, some thermal generators stop and some reduce their output.

5 types of PV design as follows are considered.

a. no-PV

b. drop-PV, which stops by voltage sag with 2 % depth or more.

c. FRT-PV, which does not stop by voltage sag.

d. delayed FRT-PV, whose output stays at zero during 0.1sec just after voltage sag.

e. DVS-PV, which supply reactive power during low voltage period just after voltage sag.

As failure, 3LG-O (three line-to-ground and open) of a circuit or 6LG-O (six line-to-ground and open) of two circuits on double circuit transmission is assumed. Fault duration time is assumed as 70msec. In some fault location unstable phenomena appear. As stabilizing measure SVC (Static Var Compensator) whose amount is proportional to PV rated output is equipped at each PV (and load) terminal. As amount of SVC increase, power system becomes stable. SVC/PV rate is set so that voltage recovers to 90% of voltage before fault by 1sec from fault occurrence. The time: 1sec corresponds to Japan FRT claim and rated compensation time of standard voltage sag compensator. Cost of SVC is almost 30 thousand yen per kVA in Japan. Thus, economical merits of DVS-PV, FRT-PV, and delayed FRT-PV cases can be calculated as reduction of SVC cost in contrast to drop-PV case. However it must be noticed that amounts of PV and SVC are proportional to each load amount. Although PV distribution must not be even, there are no data for considering uneven PV distribution. Therefore, distribution has to be considered as even. And total amount of necessary SVC will be reduced by optimal location. However, optimization is a laborious task and many times of optimization become necessary. Therefore, even SVC location is assumed here, and the identified SVC cost can be regarded as maximum value.

By the way, EAST40 and WEST40 power system models have shown distinguished unstable phenomena at 5 fault location. There may be more fault location showing instability, but they are all that were already found. The 5 examples are introduced hereafter.

［Example Power System 1］ Its structure is shown in Fig. 10.1 Peak demand of the system is 58.95GW.

3LG-O fault is assumed as F1 in the figure. Since area with gray background is consists of neighboring large loads and has very poor local generators, voltage support ability is quite low. F1 locates on a way transporting power from system edge to the area and very near to large loads. Therefore, the fault brings serious stability problem.

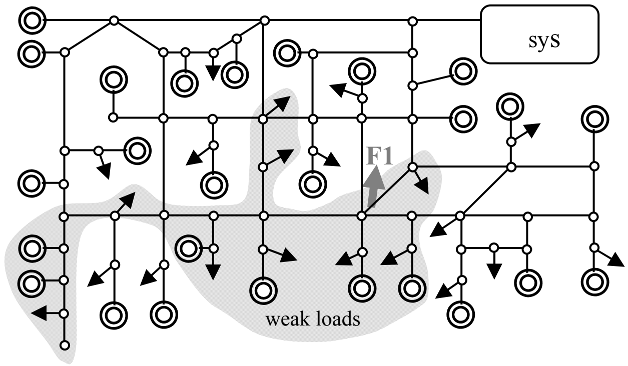

Fig. 10.1 Structure of example power system 1

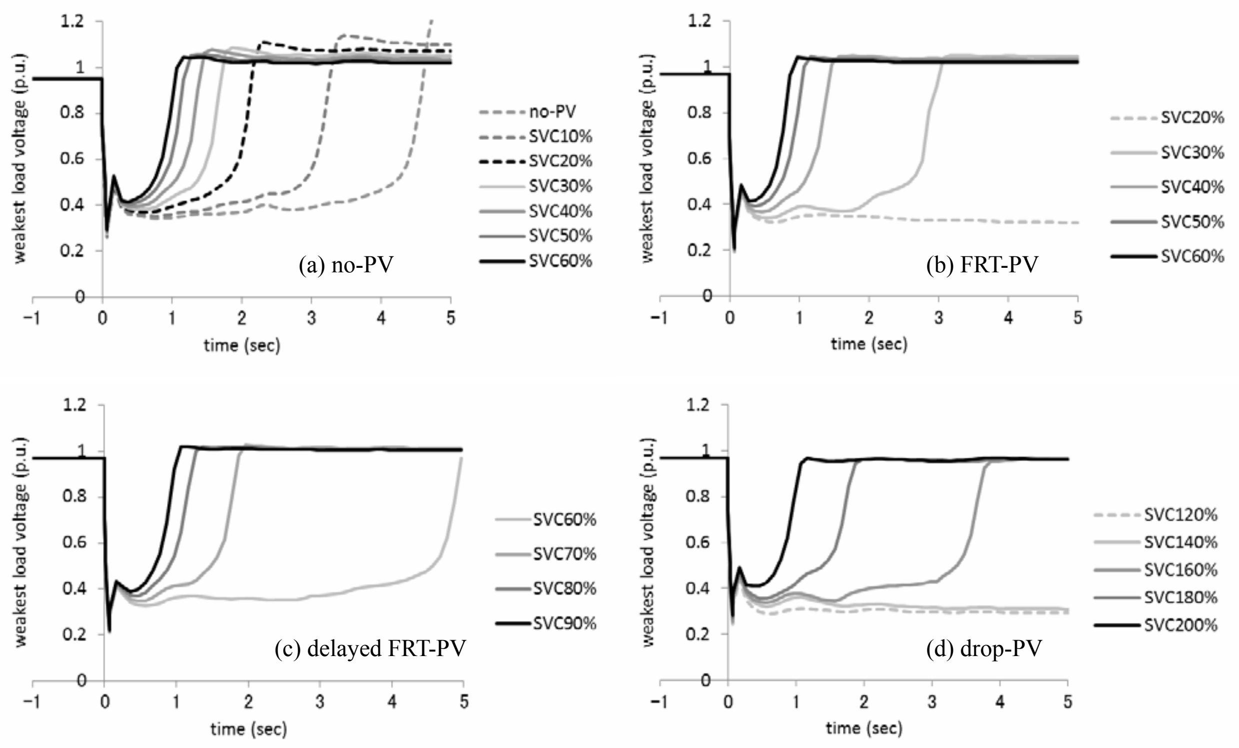

Fig. 10.2 Simulation results of example power system 1

Simulation results are shown in Fig. 10.2. Necessary amount of SVC (by PV rated output) is 60% in no-PV case, 50% in FRT-PV case, 87% in delayed FRT-PV case, and 201% in drop-PV case. Since DVS-PV includes 100% SVC within itself, necessary additional SVC is zero.

Reciprocal recovery time 1/Trec and additional SVC amount by PV amount SVC/PV are found to have good correlation as shown in Fig. 10.3, which shows no-PV case and has the

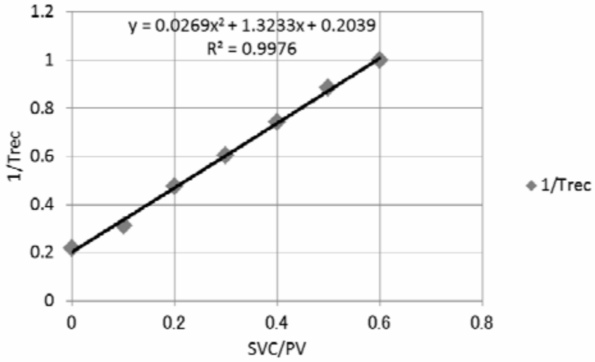

Fig. 10.3 Recovery time by SVC amount

largest number of data (7). R^2, whose ceiling value is 1, is as much as 0.9976. Therefore, variation of 1/Trec is almost perfectly accounted by SVC/PV amount. In the other cases, number of data is fewer, and R^2 is slightly larger. If number of data is 3, R^2 is 1, because it is not correlation but equation. Using the correlation function, recovery time is calculated.

［**Example Power System 2**］ Its structure is shown in Fig. 10.4. Peak demand is 29.48GW. 6LG-O fault is assumed at F1. Area with gray background interconnects to and receives much power from outer system via 2 routes: right and left. By the fault right side interconnection route is lost, and the area receives much power via only left side interconnection route. In addition, a large amount of induction motors in the area decelerate and require a lot of reactive power. Thus, voltage stability is threatened.

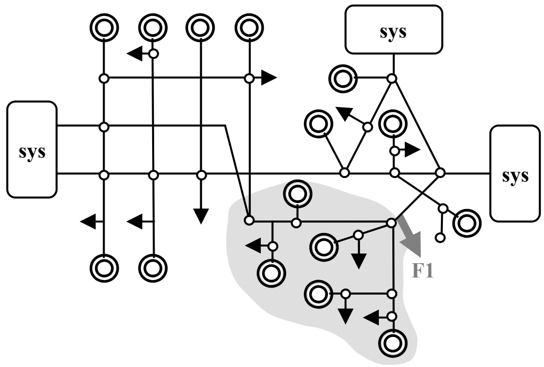

Fig. 10.4 Structure of example power system 2

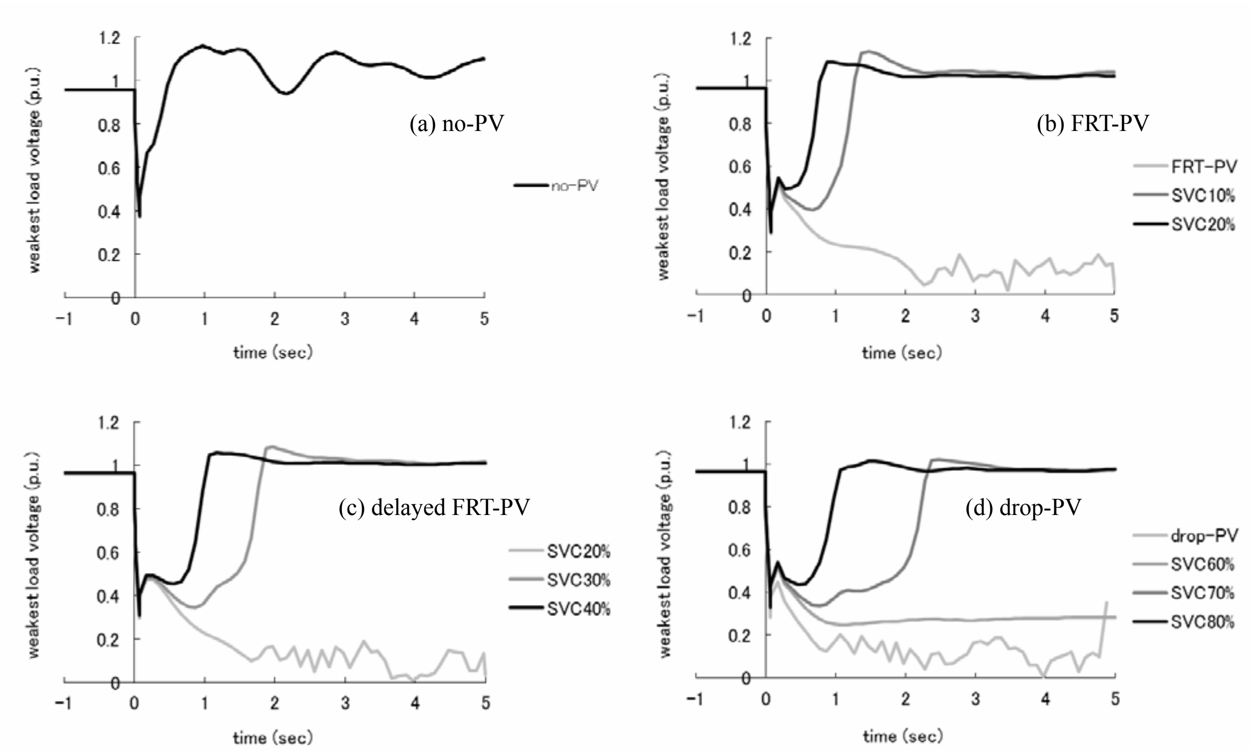

Fig. 10.5 Simulation results of example power system 2

Simulation results are shown in Fig. 10.5. Necessary amount of SVC (by PV rated output) is zero in no-PV case, 13% in FRT-PV case, 39% in delayed FRT-PV case, and 80% in drop-PV case. Since DVS-PV includes 100% SVC within itself, necessary additional SVC is zero. When amount of additional SVC is zero or small, three cases with PV show very fast voltage fluctuation, which indicates that asynchronism has occurred in generators in the area. By traditional sense asynchronism hardly appears in power receiving system. In this case, recovering induction motors draw much reactive power and result lower system voltage, which prevents power flow from generators to outside system and drives the generators to asynchronism.

［**Example Power System 3**］ Its structure is shown in Fig. 10.6. Peak demand is 25.58GW. 6LG-O fault is assumed at F1. Area with gray background interconnects to and receives small power from outside system via two routes: up and down. By fault at F1 upside interconnection route is lost. Importing power flow is small, but a load in the area is very large and has no support by local generators. By 6LG-O fault a large amount of induction motors decelerate, recover, and draw much reactive power. System voltage becomes low and voltage stability is threatened.

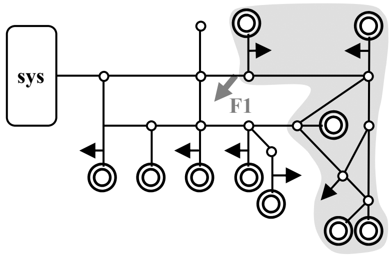

Fig. 10.6 Structure of example system 3

Simulation results are shown in Fig. 10.7. Necessary amount of SVC (by PV rated output) is zero in no-PV case, zero in FRT-PV case, 11% in delayed FRT-PV case, and 73% in drop-PV case. Since DVS-PV includes 100% SVC within itself, necessary additional SVC is zero. When amount of additional SVC is zero, drop-PV case shows very fast voltage fluctuation, which indicates that asynchronism has occurred in generators in the area. The reason why asynchronism appears even in power receiving systems is existence of induction motor loads. Since standard power system simulation in Japan never represents induction motor load, such catastrophe is overlooked.

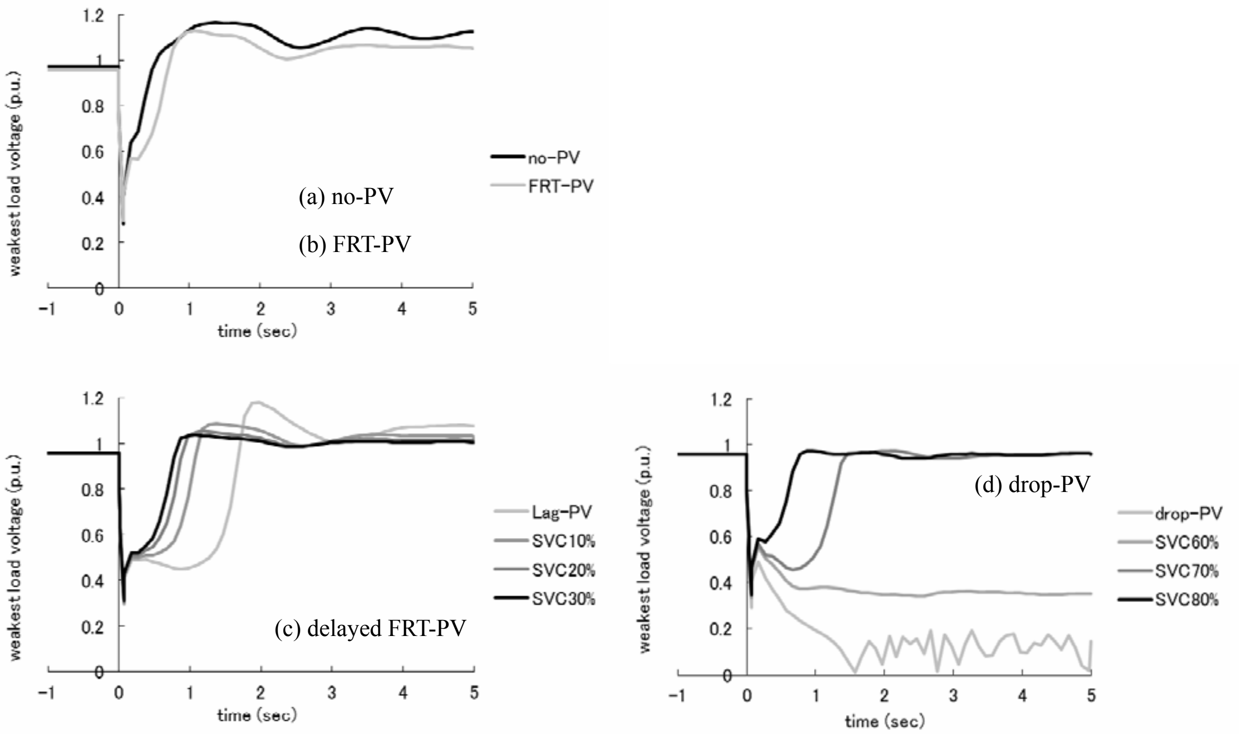

Fig. 10.7 simulation results of example power system 3

[Example Power System 4] Its structure is shown in Fig. 10.8. Peak demand is 13.66GW. The system exports much power to neighboring system. 6LG-O fault is assumed at F1. Area with gray background locates at the end and interconnects to main system via three routes. By fault at F1 most important trunk system route is lost and large power transfers to two routes in local system. Interconnecting impedance becomes very large and synchronous stability cannot be maintained. As a countermeasure a large generator G1 locating the end is separated from system at 0.2sec after the fault occurrence. Such an action is called as "Generator Shedding".

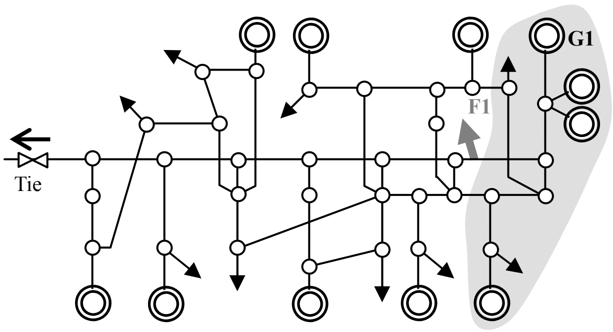

Fig. 10.8 Structure of example power system 4

Simulation results are shown in Fig. 10.9. In power sending system not only asynchronism but also poor damping appears as unstable phenomena. Also in this example power swing lasts for a long time. But poor damping is assumed to be managed by adequate design of excitation systems, especially PSS (Power System Stabilizer) setting. Necessary amount of SVC (by PV rated output) is 5% in no-PV case, zero in DVS-PV case, 59% in FRT-PV case, 78% in delayed FRT-PV case, and 159% in drop-PV case.

When amount of additional SVC is small, three cases with PV show very fast voltage fluctuation, which indicates that asynchronism has occurred in generators in the area. In no-PV case instability appears as poor damping. But in the 3 cases with PV, voltage support ability of the system is weakened because some thermal generators stop due to maintain demand supply balance. As the result, asynchronism appears as unstable phenomenon rather than poor damping.

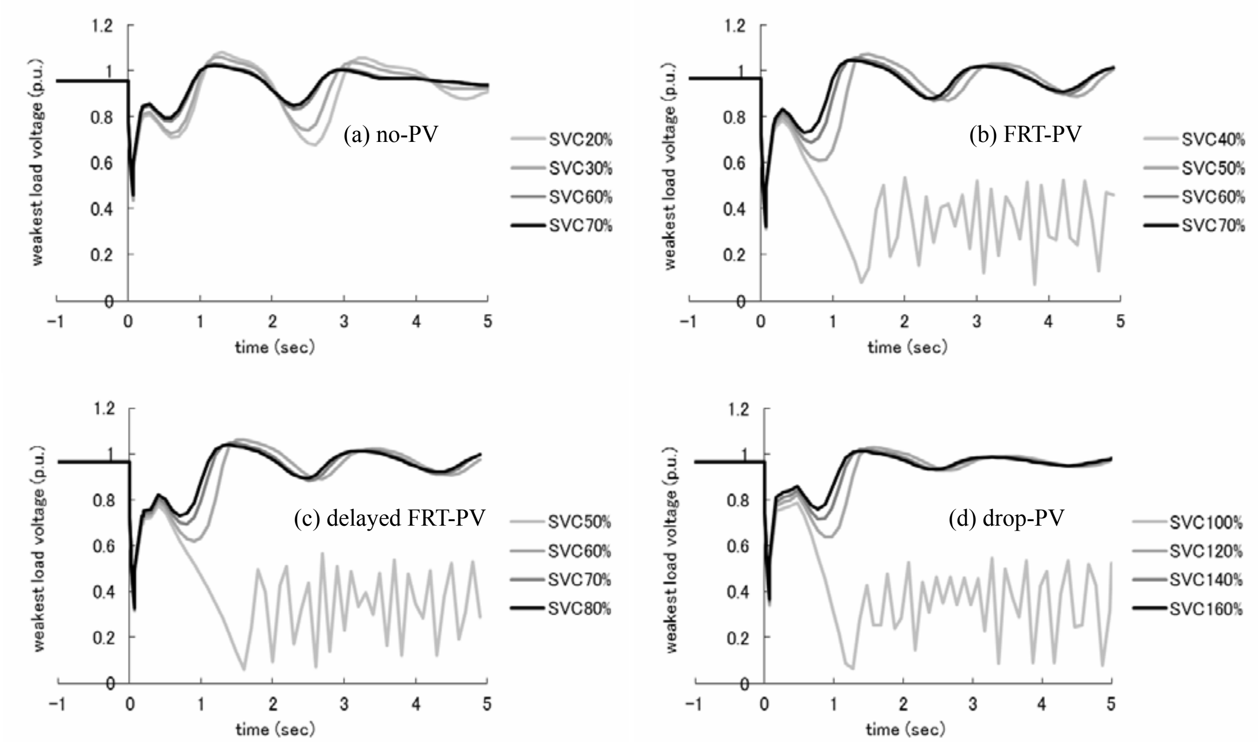

Fig. 10.9 Simulation results of example power system 4

[Example Power System 5] Its structure is shown in Fig. 10.10. Peak demand is 28.05GW. The system exports slight power to neighboring system. 3LG-O fault is assumed at F1. Area with gray background locates at the end and loads in the area are very poorly supported by their local generators. By fault at F1 induction motors in those loads decelerate, recover, and draw much reactive power. System voltage becomes lower and stability is threatened.

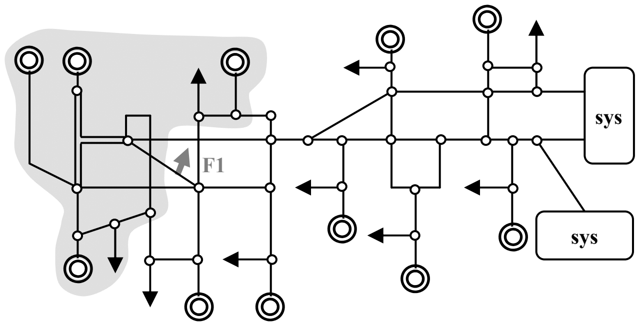

Fig. 10.10 Structure of example power system 5

Simulation results are shown in Fig. 10.11. Necessary amount of SVC (by PV rated output) is zero in no-PV case and DVS-PV case, 16% in FRT-PV case, 33% in delayed FRT-PV case, and 63% in drop-PV case.

When amount of additional SVC is small, two cases with PV show very fast voltage fluctuation, which indicates that asynchronism has occurred in generators in the area. In no-PV case instability appears as poor damping. But in the 3 cases with PV, voltage support ability of the system is weakened because some thermal generators stop due to maintain demand supply balance. As the result, asynchronism appears as unstable phenomenon rather than poor damping.

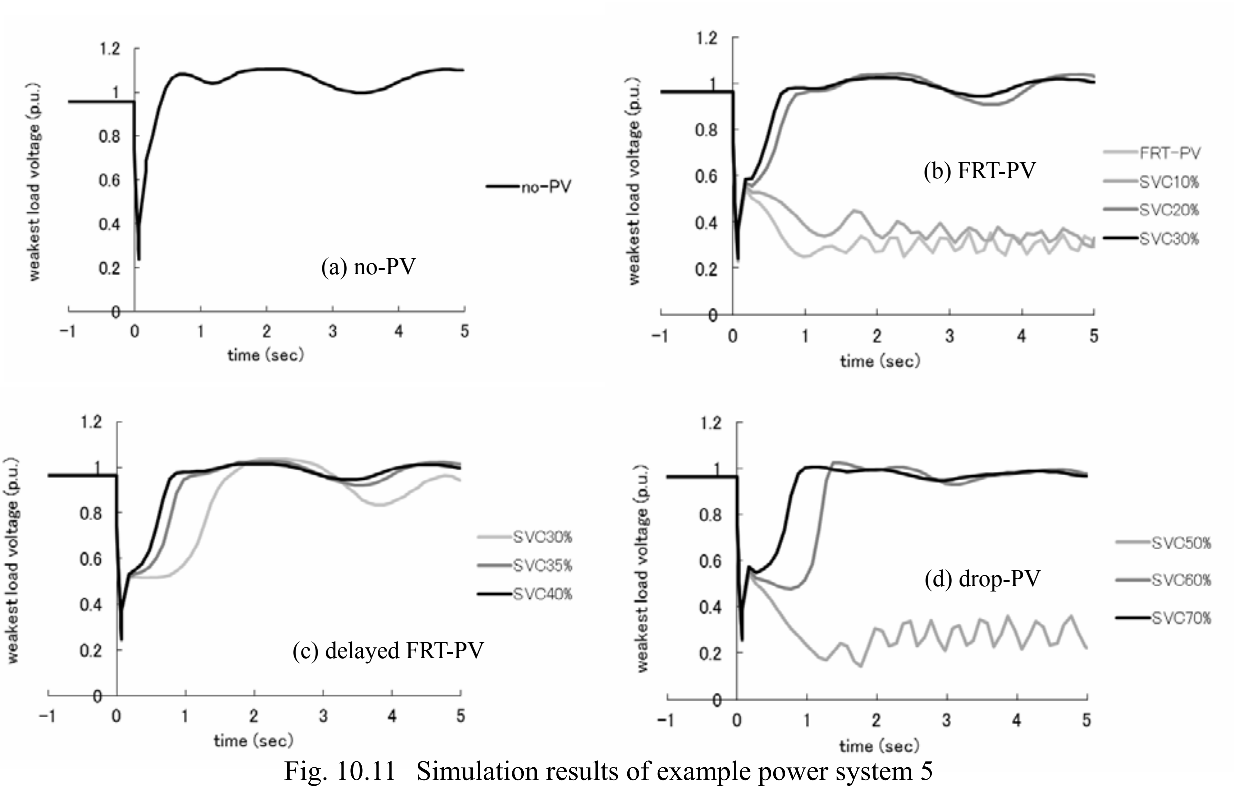

Fig. 10.11 Simulation results of example power system 5

[Economical Evaluation of FRT and DVS functions] Economical effects of FRT and DVS function in the five example systems are summarized as Table 10.1. Here,

Economical merit of DVS is evaluated as decreased SVC cost compared to FRT-type PV case.

Economical merit of FRT is evaluated as decreased SVC cost compared to drop-type PV case.

Economical merit of delayed FRT is evaluated as decreased SVC cost compared to drop-type PV case.

As a reference, economical merit of Q = -0.2P leading power factor operation is evaluated as follows.

Merit (trillion yen) = peak demand (GW) * 0.285 * 0.2 * 0.03 (trillion yen/GVA)

Table 10.1 Economical Evaluation of FRT and DVS functions

	Demand (GW)	Necessary additional SVC（by PV amount %）					Economical merit (trillion yen)			
		No-PV	DVS	FRT	del-FRT	drop-PV	DVS	FRT	del-FRT	Q=-0.2P
Ex. sys1	58.95	60	0	50	87	201	0.2520	0.7611	0.5746	0.1008
Ex.sys2	29.48	0	0	13	39	80	0.0328	0.1689	0.1033	0.0504
Ex.sys3	25.58	0	0	0	11	73	0	0.1597	0.1356	0.0437
Ex.sys4	13.66	5	0	59	78	159	0.0689	0.1168	0.0946	0.0234
Ex.sys5	28.05	0	0	16	33	63	0.0384	0.1127	0.0719	0.0480
total							0.3921	1.3191	0.9801	0.2663

The table tells that FRT function shows dominantly large economical merit. Merit of DVS is not so large. And DVS is inconsistent with some anti-islanding. Therefore, it may be wise decision not to employ DVS in PV. However, it is quite stupid not to employ FRT in PV. Delayed FRT is inferior by 0.3 trillion yen to FRT. FRT with very small delay can be realized and has been already realized by some manufacturers. Therefore, considerably delayed FRT must be rejected.

By the way, today's Japan grid code requires that PV output should recover 80% within 0.1sec after voltage recover to 90%. However, by observing behaviors of existing power system loads and adequate simulation results, the requirement is found to be nonsense. To tell the truth, system voltage just after fault clear is only 40% in very severe situation at which FRT demonstrates its merit. Even in regular situation, system voltage never recovers instantly 90% or more but recovers once 80% or so instantly and slowly increase to 100% or more (because of partial load drop by the voltage sag). The reason why such nonsense is written in grid code is misunderstanding of voltage sag concept. They believe that system voltage recovers instantly just after fault clear. The wrong belief is originated from wrong power system model: "Static Load Model" and "Traditional Aggregation Method".

Do readers consent economical merit of DG's FRT function? Do readers judge that the author has completed the account responsibility?

Negative Effect of RE's CZ Operation and Anti-Islanding

Power system stability will be much affected by whether RE operates in constant current (CI) mode or in constant impedance (CZ) mode during and just after voltage sag, and also will be slightly affected by whether "frequency feedback type with step injection" (newly developed) anti-islanding function is used (ILS) or locked (RC; Here, anti-islanding is represented by a special rotary condenser.). If stability is not sufficiently good, a certain amount of additional SVC will be needed, and the amount can be assessed by simulation, and at last, additional cost can be calculated.

Simulation was held on five subsystems in Japan. Additional SVC amount, which is expressed using ratio of SVC capacity by RE capacity (SVC/RE) that is needed for reducing recovery time to 1 sec, and additional cost are summarized in Table 10.2. Additional SVC/RE and additional cost due to CZ is expressed by mean value of ISL case and RC case. Similarly, additional SVC/RE and additional cost due to ISL is expressed by mean value of CI case and CZ case. As the result, additional cost due to CZ, sum of which reaches to 415.4 billion yen in the studied five subsystems, is far larger than that due to ISL, sum of which is 35.2 billion yen in the five subsystems. In another word, it is quite effective to design RE operates in CI mode during and just after voltage sag, and negative effect due to newly developed anti-islanding is not negligible small but not so guilty as CZ operation.

Sum of peak demand of the studied five subsystems is 135.5GW, which is 75% of peak demand of Japan. Although screening was done on the other subsystems in Japan, no unstable phenomena in usual operation were discovered. Since many cases that have been not studied exist, of course farther study must be done, however, rough understanding of additional cost will be possible by the result here introduced.

Table 10.2 Necessary additional SVC/RE ratio and cost

System	Demand (GW)	Additional SVC/RE ratio		Additional cost (billion ¥)	
		Due to CZ	Due to ISL	Due to CZ	Due to ISL
R	56.75	0.463675	0.029686	236,822	15.162
S	29.48	0.332102	-0.000560	88.113	-0.149
T	25.58	0.305542	0.005893	70.365	1.357
U	13.67	0.004640	0.070002	0.571	8.612
V	28.05	0.077386	0.040408	19.536	10.212
sum	133.50			415.407	35.183

Simulation results on the studied subsystem are shown hereafter.

[Subsystem R] Its structure is shown in Fig. 10.12. As the failure, 3LG-O on a parallel 2 circuit transmission line at F1 is given.

In area with light gray background large loads concentrate and have poor local power source. Therefore, voltage support the area becomes weak.

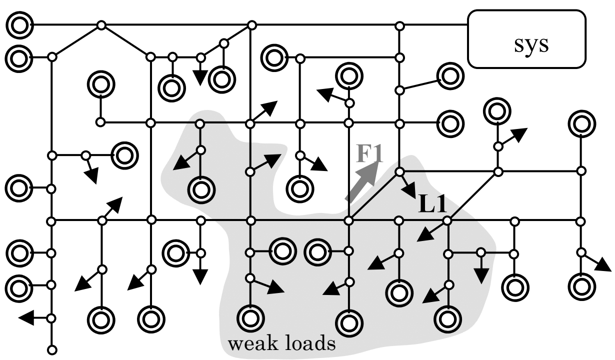

Fig. 10.12 Structure of subsystem R

Especially, load L1 having no local power source shows the slowest voltage recovery.

Simulation result of RC case is shown in Fig. 10.13, and that of ISL case is shown in Fig. 10.14. Difference between RC case and ISL case is small. CZ case shows very slower voltage recovery than CI case, and much amount of SVC is needed for improvement.

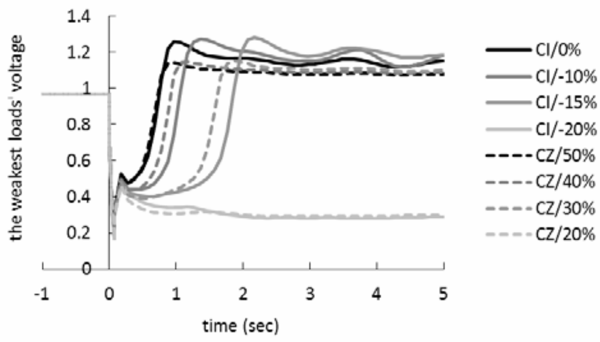

Fig.10.13 Load voltage recovery (sys R, RC)

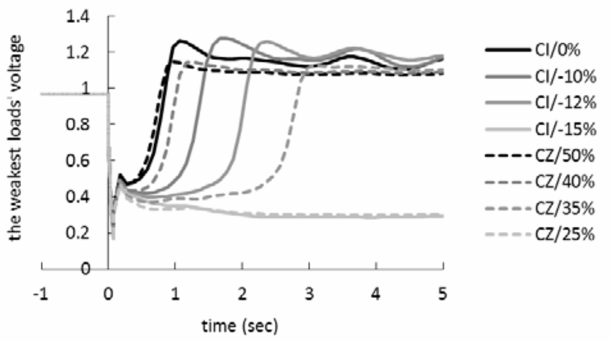

Fig.10.14 Load voltage recovery (sys R, ISL)

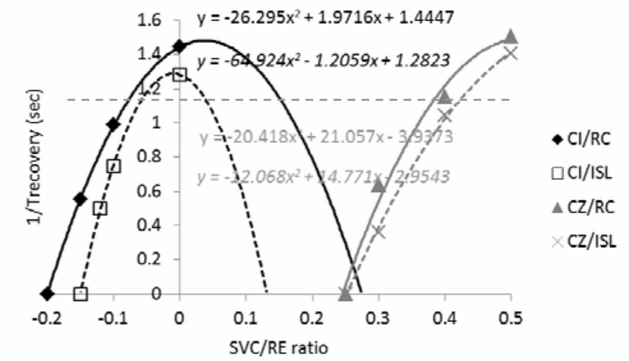

Fig.10.15 Voltage recovery time (sys R)

Reciprocal recovery time of the slowest recovered load (L1) and necessary additional SVC/RE ratio are plotted in Fig. 10.15. Data are approximated to parabolic curve, and the SVC/RE ratio that gives 1 sec recovery time is presumed. Thus, values in Table 10.2 were obtained. In subsystem R, impact due to CZ is quite heavy, and the tendency is seen also in subsystem S, T, V. For want of space, regression analyses on the other subsystem are omitted.

[Subsystem S] Its structure is shown in Fig.10.16. As the failure, 6LG-O on a parallel 2 circuit transmission line at F1 is given. By the loss of transmission route, and loop configuration is lost. The area with light gray background draws much power, and its voltage support becomes weak. Especially, load L1 that has only small capacity of local power source shows the slowest voltage recovery.

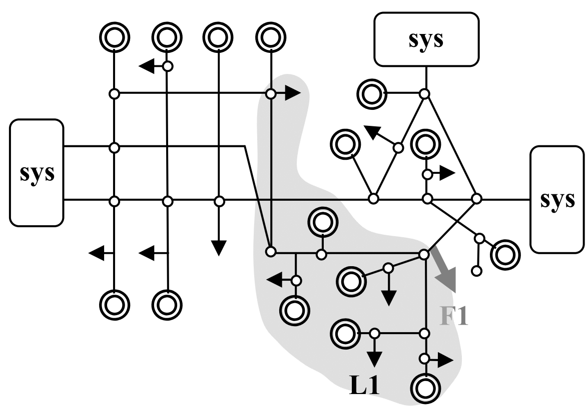

Fig.10.16 Structure of subsystem S

Simulation result of RC case is shown in Fig. 10.17, and that of ISL case is shown in Fig. 10.18. Difference between RC case and ISL case is small. CZ case shows very slower voltage recovery than CI case, and much amount of SVC is needed for improvement. The tendency that impact of CZ is dominant appears more clearly than subsystem R.

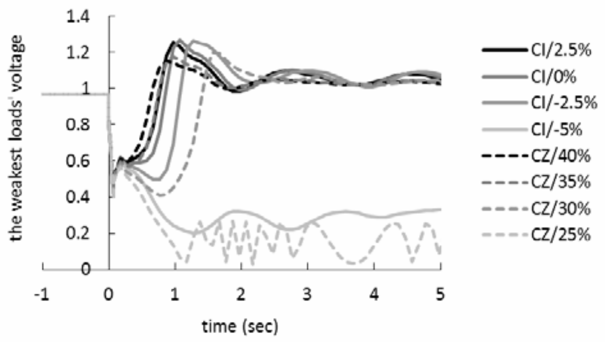

Fig.10.17 Load voltage recovery (sys S, RC)

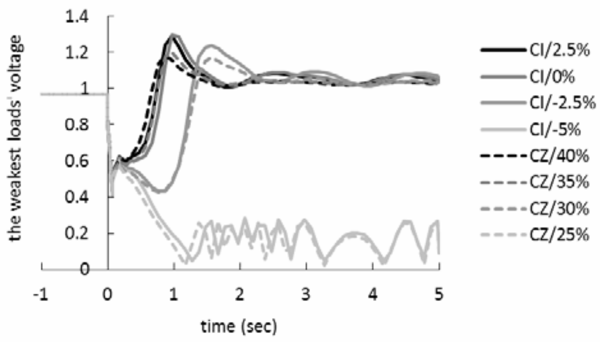

Fig.10.18 Load voltage recovery (sys S, ISL)

[Subsystem T] Its structure is shown in Fig.10.19. As the fault, 3LG-O at the secondary terminal (F1) of one of paralleled two transformers is given. As RE penetrates much, half of local thermal generators stop, and voltage support becomes weak. The secondary system studied here is not necessarily very weak. The other secondary systems that do not have powerful local power source have the same problem. In the case, of course, load L1 shows the slowest voltage recovery.

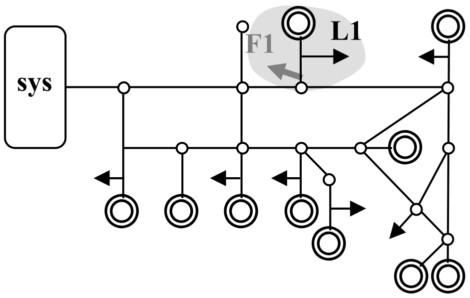

Fig.10.19 Structure of subsystem T

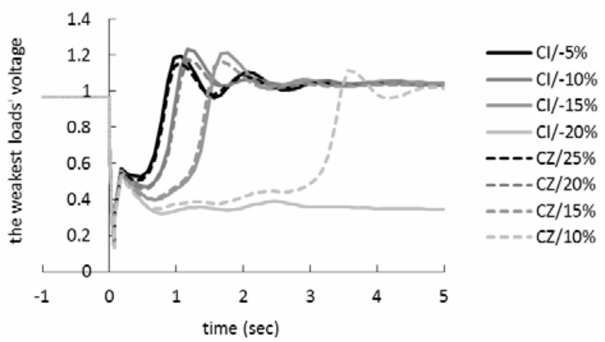

Fig.10.20 Load voltage recovery (sys T, RC)

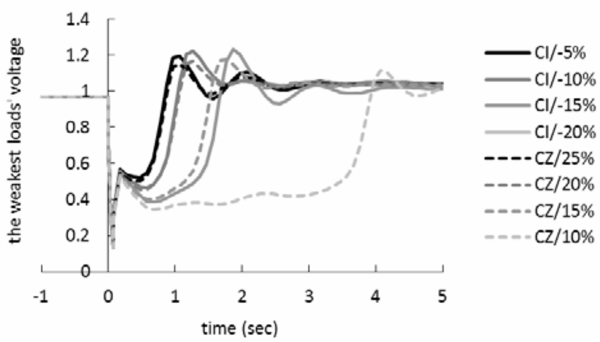

Fig.10.21 Load voltage recovery (sys T, ISL)

Simulation result of RC case is shown in Fig. 10.20, and that of ISL case is shown in Fig. 10.21. Difference between RC case and ISL case is small. CZ case shows very slower voltage recovery than CI case, and much amount of SVC is needed for improvement. The tendency that impact of CZ is dominant also appears more clearly than subsystem R.

[Subsystem U] Its structure is shown in Fig. 10.22. as the failure, 6LG-O on a double circuit transmission line at F1. Main transfer route is lost, power flow on the route shifts to secondary network, and oscillatory stability is threatened. For maintaining stability, generator G1 is tripped 0.2 sec after the fault occurrence. By significant power swing, load L1 at the end of interconnection shows the largest voltage deviation.

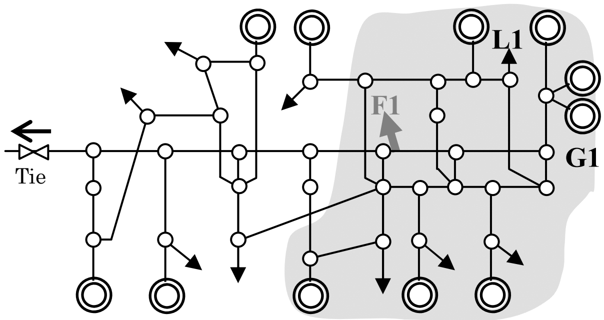

Fig.10.22 Structure of subsystem U

Simulation result of RC case is shown in Fig. 10.23, and that of ISL case is shown in Fig. 10.24. On the contrary of the former three cases, in which voltage and transient stability were dominant problems, oscillatory stability is the dominant problem in the case. Unless power swing does not grow, load voltage always recovers to 0.85 or more within 1 sec. Therefore, minimum additional SVC amount with which power swing never grow is the answer to be searched. Difference between CI case and CZ case is small. ISL case shows slightly inferior stability than RC case. ISL spoils stability in the case.

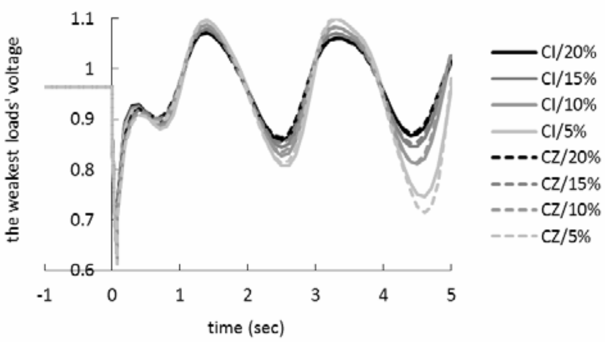

Fig.10.23Load voltage recovery (sys U, RC)

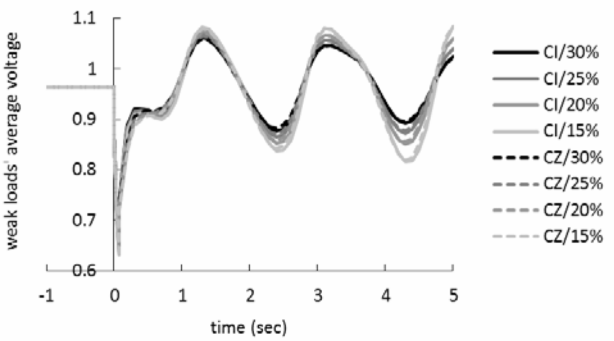

Fig.10.24 Load voltage recovery (sys U, ISL)

[Subsystem V] Its structure is shown in Fig. 10.25. As the failure, a 3LG-O on a double circuit transmission line at F1 is given. Similarly to subsystem U, oscillatory stability is threatened. However, it is quite unique that load L1 that locates not nearby the failure but locates almost on the power swing locus shows the largest voltage deviation.

Simulation result of RC case is shown in Fig. 10.26, and that of ISL case is shown in Fig. 10.27. Only in the case, voltage recovery time is

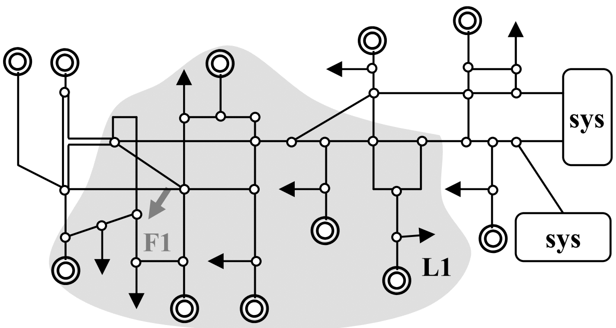

Fig.10.25 Structure of subsystem V

defined as the time that voltage swing envelope bottom exceeds 0.85, and the minimum additional SVC amount that makes the recovery time within 1 sec is calculated. Difference between RC case and ISL case is small. On the contrary, CZ case shows much worse result than CI case. In the case, voltage stability induced by very large power swing is dominant problem. Therefore, voltage stability is more serious than oscillatory stability.

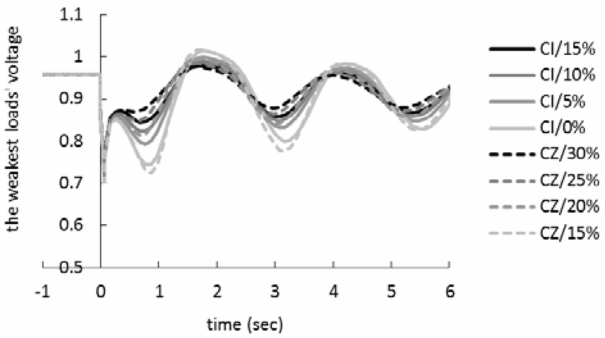

Fig.10.26 Load voltage recovery (sys V, RC)

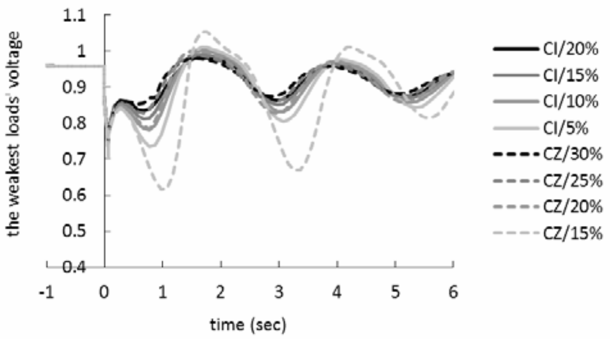

Fig.10.27 Load voltage recovery (sys V, ISL)

Impact of RE Current Recovery Delay

Also in the case that RE current recovery delays than voltage recovery, some negative effect will appear. As an example, simulation result on subsystem R is shown in Fig. 10.28. Negative effect of RE current interruption during 0.1 sec just after failure clearance is assessed by necessary additional SVC amount. As the result, SVC/RE becomes around 20% larger than no current interruption case.

However, it must be noticed that the example system is quite large, and as the result, partial load drop except the 9 loads with light gray background cannot represent by restraint of the simulation tool. As the result, necessary SVC/RE amount in the base (no current interruption) case is calculated as around 5% larger than the result shown in Fig. 10.13. For such a difficulty, making difference from the base case will be convenient.

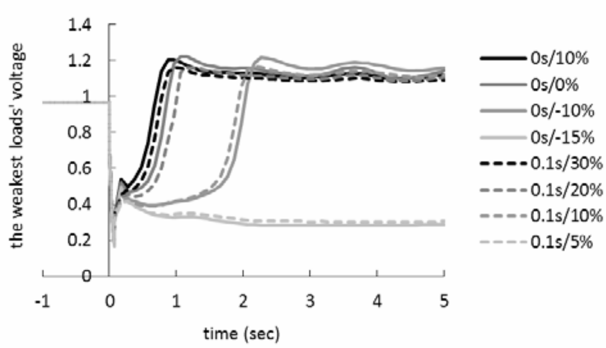

Fig.10.28 Load voltage recovery (sys R, delay)

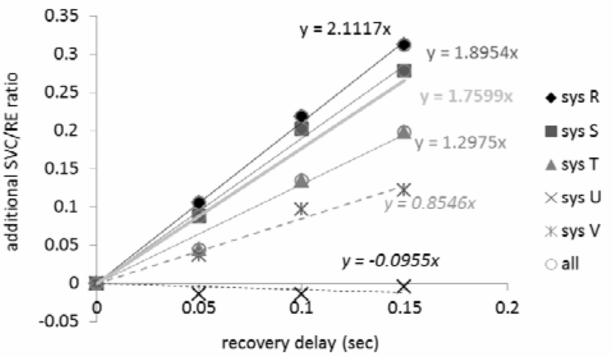

Fig.10.29 Additional SVC due to recovery delay

For want of space simulation results of the other examples are omitted. Instead, impact of RE current interruption duration is studied. Simulations were made on the five subsystems with 0 sec, 0.05 sec, 0.1 sec, and 0.15 sec RE current recovery delay. The result is shown in Fig. 10.29. Additional SVC/RE is almost proportional to recovery delay. Subsystem R, S, T where transient/voltage stability is most threatened show the same tendency. Subsystem U where oscillatory stability is most threatened shows very little harm of recovery delay. Subsystem V where both transient/voltage and oscillatory stabilities becomes questionable shows the intermediate tendency.

Additional SVC/RE and cost with 0.1 sec RE recovery delay is summarized in Table 10.3. As a reference, those due to CZ (in the former section) reappears. Additional cost due to 0.1 sec recovery delay is calculated as 233.6 billion yen, which is around 56% of the harm due to CZ, and is said as considerably large.

Table 10.3 Impact due to RE's 0.1sec recovery delay

System	Demand (GW)	Additional SVC/RE ratio		Additional cost (billion ¥)	
		Due to CZ	Due to delay	Due to CZ	Due to delay
R	56.75	0.463675	0.218663	236,822	111.682
S	29.48	0.332102	0.202387	88.113	53.697
T	25.58	0.305542	0.197673	70.365	45.508
U	13.67	0.004640	-0.013650	0.571	-1.679
V	28.05	0.077386	0.096726	19.536	24.418
sum	133.50			415.407	233.626

Remark

Although DVS function of RE is quite effective for improving power system stability, its adoption does not realize in Japan because of inconsistency with anti-islanding made by only RE side. However, RE that can maintain constant current operation even in low voltage situation has "Dynamic Current Support" function, which contributes to good power system stability even if the contribution is not so much as DVS. In another word, such RE that shifts to constant impedance (CZ) mode in low voltage situation for avoiding over-current does not use its inherent PCS capacity for power system stability. In addition, 0.1 sec RE current recovery delay in case of voltage sag brings 56% harm of CZ type. Thus, excessive protection of PCS hinders effective use of PCS capacity, and therefore, is harmful for power system stability.

By simulation on models of 50Hz and 60Hz interconnection in Japan, additional SVC cost due to CZ instead of CI is found to be 415.4 billion yen. Therefore, it seems favorable apply "top runner doctrine" to RE design. However in Japan, the doctrine seems to be regard as a special hard treatment for energy saving and electric power industry. Therefore instead of the doctrine, it may be suitable to classify PCS into a few ranks of "Dynamic Current Support" capability in "Grid Code", and burden interconnection charge to lower rank PCS.

In this occasion, negative effect due to anti-islanding is studied. Large negative effect is not found except subsystem U where oscillatory stability is critical. Total additional cost in the studied five subsystems is 35.2 billion yen, which is much smaller than that due to CZ operation. However, studied cases here are few. More case study must be performed.

In these analyses like FRT merit evaluation, realistic power system model is indispensable [1-5]. Especially, it is fatally important to consider induction motor load that consumes 50% or more electric power and load branch impedance that represents secondary and distribution network from 66kV class bus to load terminal. If they are not considered, negative effects of PCS without FRT capability, CZ operation during low voltage, and delay in RE output recovery after voltage sag are masked. The important two issues in power system model are rigorously studied in US and EU, except only Japan in developed countries. The defect may spoil such as consulting business for developing countries. Quick catch up seems to be urgent.

Moreover in this occasion, it must be pointed out that some specialists on electric power system must attend to such committees where "Grid Code" is established.

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