10. Effect of FRT in RE

Japan grid code[1] claims RE (Renewable Energy) FRT (Fault Ride-Through) function, but does not claim DVS (Dynamic Voltage Support) function. In some European countries not only FRT function but also DVS function are claimed[2]. One reason why DVS function is not claimed in Japan is that co-usability of DVS function and active type anti-islanding ,which must be achieved by RE side only in Japan, is doubtful and research around the co-usability has not begun yet. Therefore, whether present Japan grid code makes generally proper claim or not must be once verified.

For the purpose, a difficult work to presume value of FRT and DVS must be accomplished. Crtainly, Value of FRT and DVS can be evaluated by amount (cost) of reduced equipment (here, SVC, Static Var Compensator) by those function.

However, there are three difficulties as follows exist in the evaluation.

1) Examined power system must not be fictional model system but must be existing power system.
2) Many pairs of RE and SVC are become object of analysis. Optimal SVC distribution that can maintain power system stability at any fault location must be obtained.
3) The optimal SVC distribution must maintain power system stability for any power flow scene during one year or more.

No human being can obtain strict optimal solution for such a difficult issue. However, practical and profitable semi-optimal solution may be obtained.

Method for evaluating merit of FRT and DVS

Three reasons why evaluating merit of FRT and DVS is difficult is stated above. Here, countermeasure for the difficulties are quested for[3].

Existing system model There are IEEJ EAST30 and WEST30 power system model, which seems as if they preserve existing 500kV interconnection[4]. However, they include flaws: modeling of 500kV system is insufficient, the report told that they do not preserve existing system's character, static loads without induction motor are directly connected to 66kV class bus. It is reported that evaluation of FRT merit varies largely by modeling or ignoring induction motor load[5]. Thus, they are inadequate as existing power system model.

The author built EAST40 and WEST40 as adequate existing power system model compensating those flaws above. They are used here. 500kV network is almost perfectly modeled. Dynamic character of power system such as excitation system are presumed by Y-connection aggregation[6]. Load is modeled as mix of 50% induction motor and 50% impedance connected via load branch to 66kV class bus. From voltage sag measurement[7], induction motor ratio (motor consuming kW/load consuming kW) is set as 50%, inertia is set as 0.5sec, and loading (motor consuming kW/motor capacity kVA) is set as 50%.

Since scientific paper must prepare reproducibility, as a matter of course, minute data of EAST40 and WEST40must be published. Although volume of those data is quite large, the size can be overcome by many pages. However, utilities cannot publish minute power system data for social safety.

The difficulty is thought as follows. There are many engineers having minute data of existing power system. By researches up to now it was found that load branch impedance from 66kV class bus to load is almost 3.5 + j17.5%

at peak demand base(6). By adding the load branch impedance to data owned by them, and by applying Y-connection aggregation onto the data, power system model quite similar to EAST40 and WEST40 can be built. If not perfect, but reproducibility is considerably fulfilled.

Optimal distribution of SVC Fault can occur everywhere in existing power system. As nearer the load locates to fault, as much motor decelerates and voltage recovery delays. Therefore, to distribute SVC proportional to load amount has some propriety. Of course exceptions exist. Motors nearby powerful local generator will not decelerates much. However, consideration those exception is regarded as next step here, and such minute and strict optimization is not held here.

First, simulation is performed with SVCs whose amount is proportional to load amounts by applying fault to all guessed weak points. The weakest point that shows the longest time for all loads' voltage recovery can be selected

Next, ratio of SVC amount to load amount is adjusted so that voltage recovery time of all loads by fault at the weakest point becomes one sec. Total SVC amount then is identified as necessary SVC amount. The reason why voltage recovery time is one sec is that Japan grid code decided FRT duration tine as one sec. If low voltage continues more than one sec, FRT may be abandoned in many REs, as the result, there is considerable risk that the system may go to voltage collapse. Aside, Japan grid code decides MV connected RE's FRT duration as 0.3 sec. This is too short, understood by simulation results hereafter, and considering behavior of existing power systems at their stability limit. Therefore, neglected.

Thus obtained SVC distribution is, of course, not the strict optimal solution but a semi-optimal solution. However, since all loads' voltage recover within one sec, it is certainly an enough condition. For power system operators, even if the SVC distribution is not strictly optimal, can be accepted as semi-optimal solution only if it is enough condition. Of course more minute optimization is valuable, speed of preparing solution is also valuable. Optimization is recognized a matter of invention by engineers, and further consideration is omitted here.

Considering all power flow scenes Fault can occur every time in existing power system. Because human error and GIS internal fault can occur in every season and every weather. Therefore, target performance must be realized in every power flow scene. To confirm it, simulation in infinite cases must be performed. It seems ridiculous. Some invention is needed.

Synchronous stability is most severe at peak demand scene because generator's internal angle leads most. However, spec and location of generators are different by time, therefore, scene where stability is most severe cannot be identified. To simulate every month's peak demand scene may be necessary for example.

However, modeling induction motor load, circumstance is changed. Two major rotating machine in power system: synchronous generator and induction motor reduce synchronous stability and fast voltage stability each other by mechanism as shown Fig. 5.1(8). In case studies hereafter, instability is mainly caused by induction motor's voltage instability, and synchronous instability is the result. This is proved by stabilizing effect of SVC located not at generator but at load. Since SVC prevents

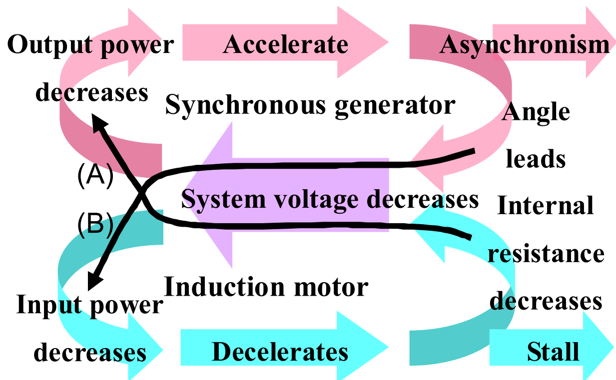


Fig 5.1(again) Mechanism destroying transient stability

voltage instability of induction motor load, generator's synchronous instability is avoided as result.

It is peak demand when voltage stability becomes most severe, because in the scene downward power flow from trunk system to load becomes maximum. Therefore, in case that instability is broken by motor's voltage instability as trigger, it is sufficient to consider only yearly peak demand scene.

Merit index of FRT and DS

Since one of a major merits of RE is to locate nearby load, RE is assumed to distribute proportional load amount making the ideal merit as start point. The proportional coefficient is chosen as 0.285, which corresponds 53GW in Japan. As result, RE amount is proportional to SVC amount, and SVC amount is ratio to RE amount hereafter.

Three RE designs as follows are assumed.

1) Drop type: stops due to voltage sag.

2) FRT type: does not stop due to voltage sag. FRT duration time is assumed as infinite.

3) DVS type: does not stop due to voltage sag, and generates reactive power Q as follows.

$$Q = W \left\{ \left(\frac{V}{V0} \right)^{12} - \left(\frac{V}{V0} \right)^{2} \right\} \qquad (10.1)$$

Here, W is rated output of RE, V is voltage during fault, V_0 is voltage before sag. The DVS function generates maximum reactive power 0.582 of W at V is 0.84. Also SVC has the same character as DVS. That is, DVS type is equal to FRT type with SVC having the same capacity of RE.

Fault is modeled at most three-phase-to-ground followed one bus (or circuit, bank) missing (3LG-O) and fault clear in radial system, or three-phase-to-ground followed route missing (6LG-O) in loop system

Case study

In model of existing power system built by the author, significant instabilities that need much SVC in five subsystems. They are introduced as follows.

Subsystem 1 Its structure is shown in Fig. 10.1. As the area with gray background has much load and poor local power source, voltage recovery of induction motor load is slow. As severe fault 3LG-O at F1 is assumed.

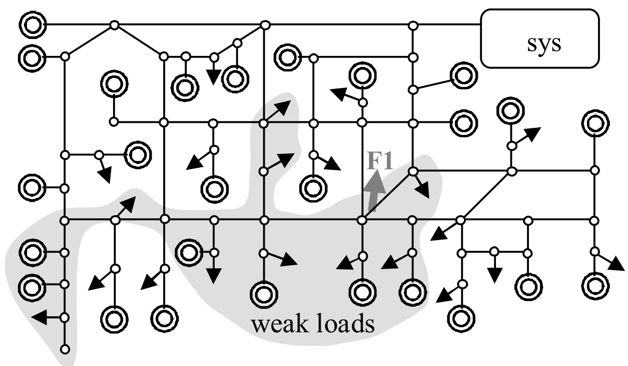


Fig. 10.1 Structure of subsystem 1

In drop type RE case, voltage profile of the slowest load recovery is shown in Fig. 10.2 by varying SVC amount.

In FRT type RE case, voltage profile of the slowest load recovery is shown in Fig. 10.3 by varying SVC amount.

In voltage recovery cases, relationship of recovery time to 80% voltage and SVC/RE amount ratio and are plotted as Fig. 10.4. By parabolic approximation, SVC amount that is needed for realizing 1 sec recovery time.

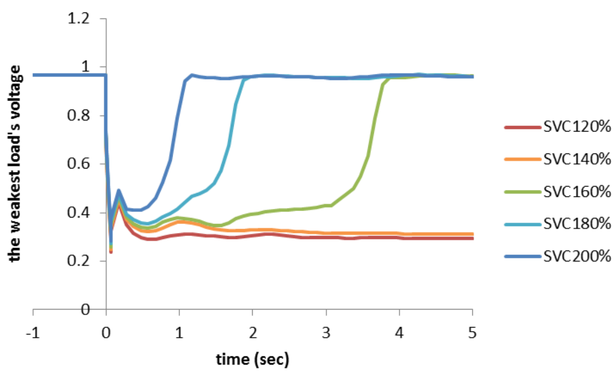


Fig. 10.2 Voltage recovery profile (sys1, drop)

Needed SVC is 201% of RE amount in drop type RE case, and 50% in FRT type case. Since DVS type is FRT typr with 100% SVC, no SVC is needed in DVS type RE case.

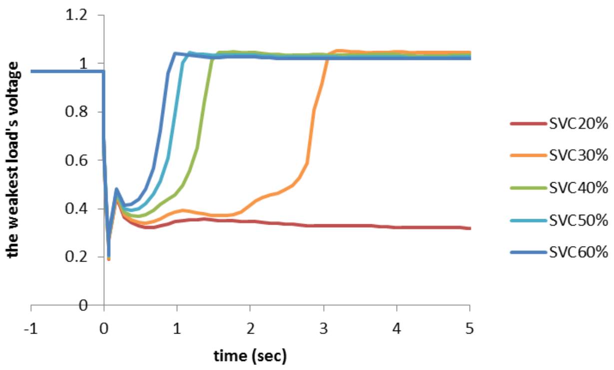
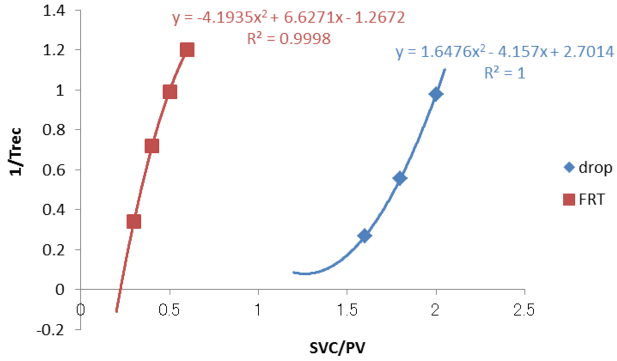


Fig. 10.3 Voltage recovery profile (sys1, FRT)



Fig, 10.4 Voltage recovery time by SVC/RE ratio (sys1)

Subsystem 2 Its structure is shown in Fig. 10.5. Area with gray background has much load and poor local power source, therefore voltage recovery delays. As severe fault 6LG-O at F1 is assumed.

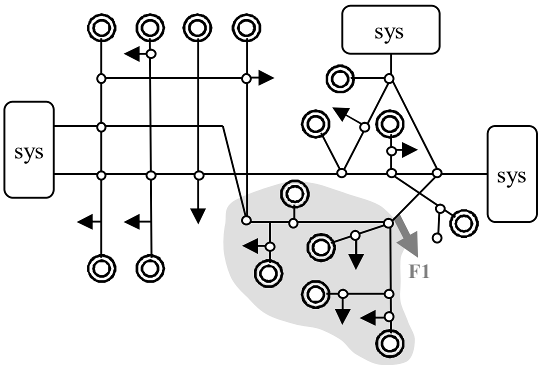


Fig. 10.5 Structure of subsystem 2

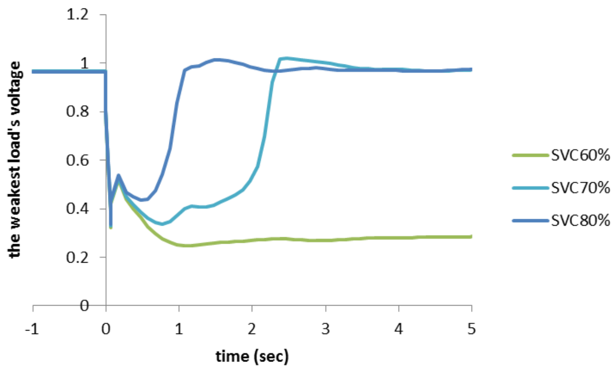


Fig. 10.6 Voltage recovery profile (sys2, drop)

In drop type RE case, voltage profile of the slowest load recovery is shown in Fig. 10.6 by varying SVC amount.

In FRT type RE case, voltage profile of the slowest load recovery is shown in Fig. 10.7 by varying SVC amount.

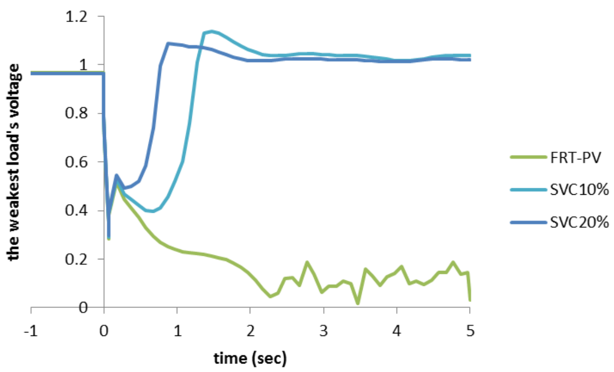
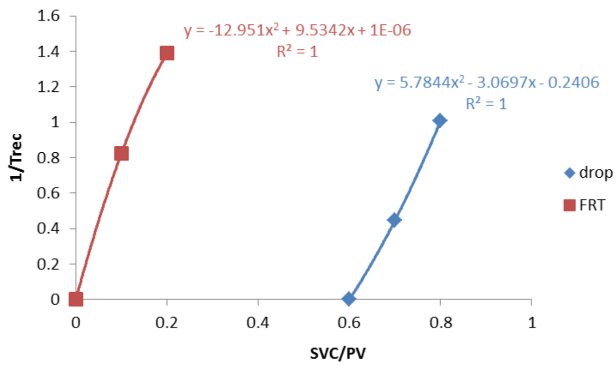


Fig. 10.7 Voltage recovery profile (sys2, FRT)



Fig, 10.8 Voltage recovery time by SVC/RE ratio (sys2)

In voltage recovery cases, relationship of recovery time to 80% voltage and SVC/RE amount ratio and are plotted as Fig. 10.8. By parabolic approximation, SVC amount that is needed for realizing 1 sec recovery time. Needed SVC is 80% of RE amount in drop type RE case, and 13% in FRT type case. Since DVS type is FRT type with 100% SVC, no SVC is needed in DVS type RE case.

Subsystem 3 Its structure is shown in Fig. 10.9. Area with gray background has much load and poor local power source, therefore voltage recovery delays. As severe fault 6LG-O at F1 is assumed.

In drop type RE case, voltage profile of the slowest load recovery is shown in Fig. 10.10 by varying SVC amount.

In FRT type RE case, voltage profile of the slowest load recovery is shown in Fig. 10.11 by varying SVC amount.

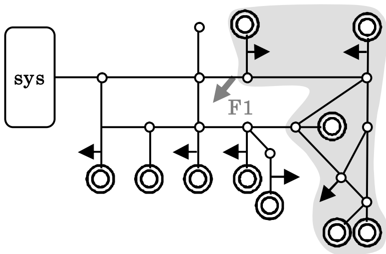


Fig. 10.9 Structure of subsystem 3

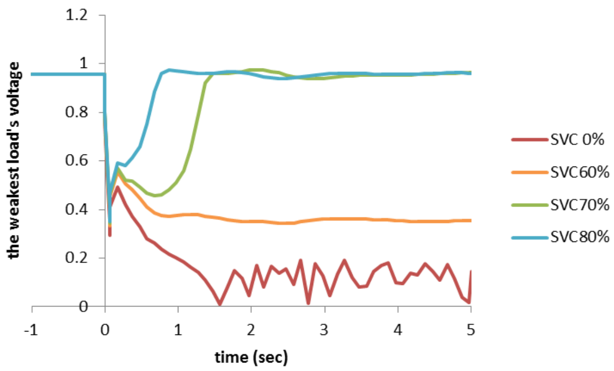


Fig. 10.10 Voltage recovery profile (sys3, drop)

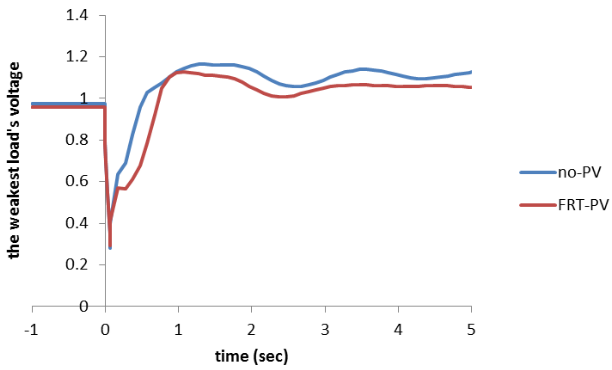
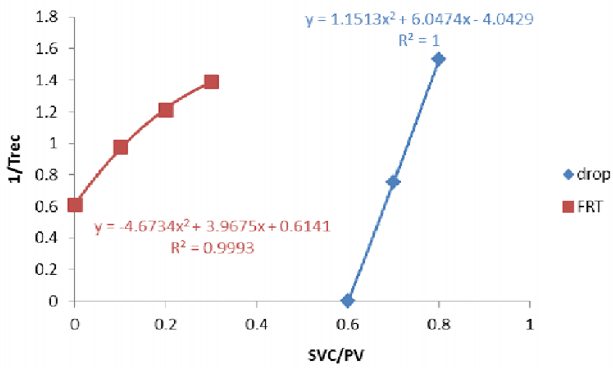


Fig. 10.11 Voltage recovery profile (sys3, FRT)

In voltage recovery cases, relationship of recovery time to 80% voltage and SVC/RE amount ratio and are plotted as Fig. 10.12. By parabolic approximation, SVC amount that is needed for realizing 1 sec recovery time. Needed SVC is 73% of RE amount in drop type RE case, and 0% in FRT type case. Since DVS type is FRT type with 100% SVC, no SVC is needed in DVS type RE case.



Fig, 10.12 Voltage recovery time by SVC/RE ratio (sys3)

Subsystem 4 Its structure is shown in Fig. 10.13. Area with gray background has much load and poor local power source, therefore voltage recovery delays. As severe fault 6LG-O at F1 is assumed.

In drop type RE case, voltage profile of the slowest load recovery is shown in Fig. 10.14 by varying SVC amount.

In FRT type RE case, voltage profile of the slowest load recovery is shown in Fig. 10.15 by varying SVC amount.

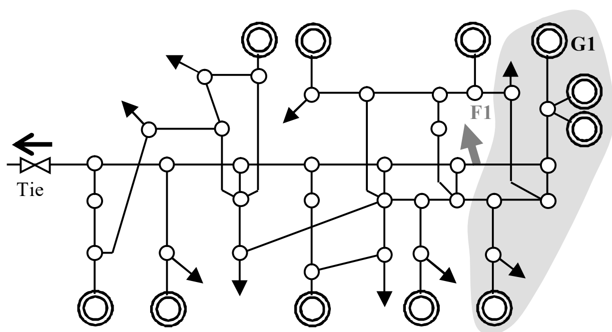


Fig. 10.13 Structure of subsystem 4

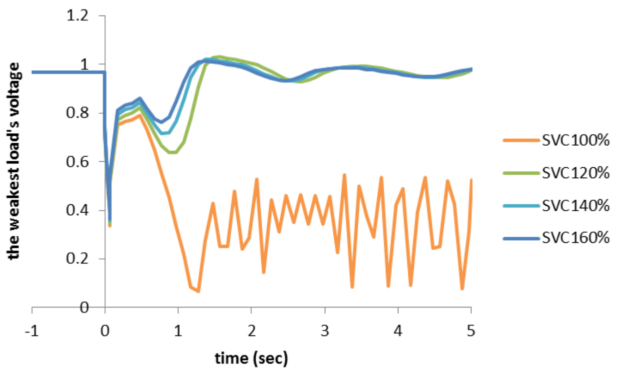


Fig. 10.14 Voltage recovery profile (sys4, drop)

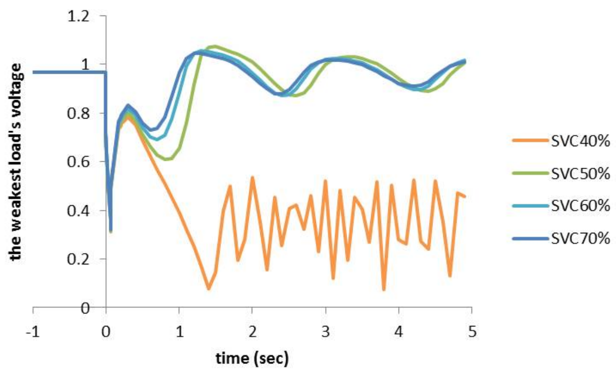
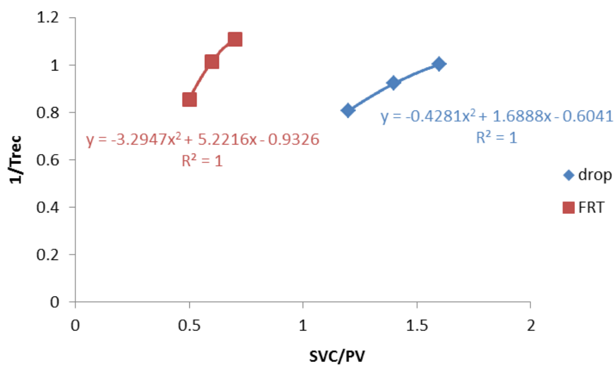


Fig. 10.15 Voltage recovery profile (sys4, FRT)

In voltage recovery cases, relationship of recovery time to 80% voltage and SVC/RE amount ratio and are plotted as Fig. 10.16. By parabolic approximation, SVC amount that is needed for realizing 1 sec recovery time. Needed SVC is 159% of RE amount in drop type RE case, and 59% in FRT type case. Since DVS type is FRT type with 100% SVC, no SVC is needed in DVS type RE case.



Fig, 10.16 Voltage recovery time by SVC/RE ratio (sys4)

Subsystem 5 Its structure is shown in Fig. 10.17. Area with gray background has much load and poor local power source, therefore voltage recovery delays. As severe fault 3LG-O at F1 is assumed.

In drop type RE case, voltage profile of the slowest load recovery is shown in Fig. 10.18 by varying SVC amount.

In FRT type RE case, voltage profile of the slowest load recovery is shown in Fig. 10.19 by varying SVC amount.

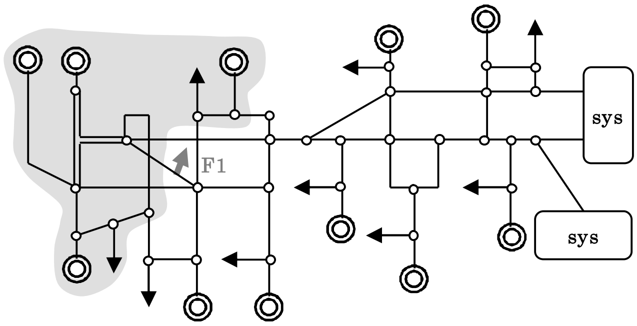


Fig. 10.17 Structure of subsystem 5

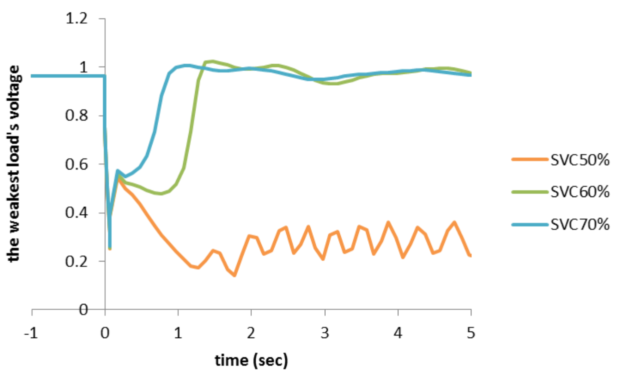


Fig. 10.18 Voltage recovery profile (sys5, drop)

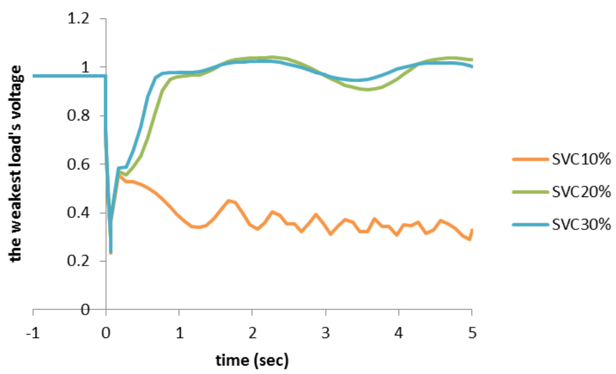
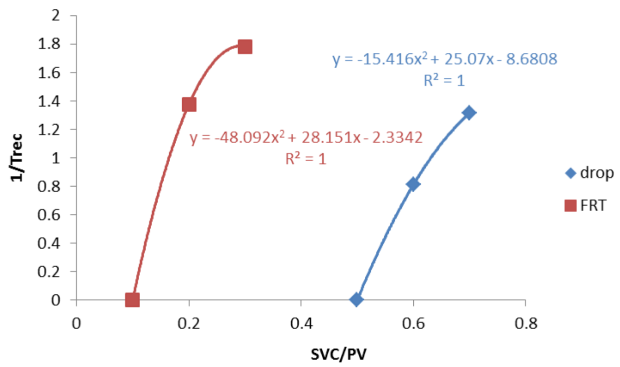


Fig. 10.19 Voltage recovery profile (sys5, FRT)

In voltage recovery cases, relationship of recovery time to 80% voltage and SVC/RE amount ratio and are plotted as Fig. 10.20. By parabolic approximation, SVC amount that is needed for realizing 1 sec recovery time. Needed SVC is 63% of RE amount in drop type RE case, and 16% in FRT type case. Since DVS type is FRT type with 100% SVC, no SVC is needed in DVS type RE case.



Fig, 10.20 Voltage recovery time by SVC/RE ratio (sys5)

Merit comparison of FRT vs. DVS

Results of the five case studies are summarized in left half in Table 10.1. Here, SVC cost is assumed as 30million yen/GVA, FRT value of subsystem1 is calculated as

58.95 * 0.285 * (2.01 – 0.50) * 30 = 761 billion yen

Also DVS value of subsystem 1 is calculated as

58.95 * 0.285 * (2.01 – 0.00) * 30 = 252 billion yen

Total value in the five subsystem of FRT is 1319 billion yen and that of DVS is 392 billion yen. Value of FRT is much larger than DVS value.

Table 10.1 Necessary SVC/RE ratio and value of FRT and DVS

sys	Demand (GW)	SVC/RE (%)		merit (billion yen)	
		drop	FRT	FRT	DVS
1	58.95	201	50	761.073975	252.01125
2	29.48	80	13	168.87618	32.76702
3	25.58	73	0	159.65757	0
4	13.66	159	59	116.793	68.90787
5	28.05	63	16	112.718925	38.3724
	sum			1319.11965	392.05854

Closing

Using existing power system model values of FRT and DVS are evaluated. FRT value was 1319 billion yen, and DVS value was 392 billion yen. Therefore, Japan grid code that claims only FRT but does not claim DVS has some reason.

Also, necessity and difficulty of adopting adequate model of existing power system are explained, and some solutions solving the difficulty are presented and demonstrated on five example systems.

RE has various hidden capability that is not claimed in Japan grid code. Especially power electronics equipment such as inverter can, if controlled adequately and combined some battery, make various contribution: DVS, short term power regulation, governor free, spinning reserve, imaginary inertia, and imaginary electro motive force for improving stability of power system. Various condition improvement so that not only carbon free kWh value but also various potential values of REs are realized, and that high performance REs can receive propriety return.

Grid code is the core. Not only limited point of view such as network protection, but also viewpoint of impact and contribution to power system assessed on existing power system model, grid code should be refined. Continuous effort is needed toward low carbon society through not only law and system as legal violence but also technical, practical, and economical concrete contribution.

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