

A General Framework for Power System Transient Stability Control

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Abstract: The question of transient stability control is revisited, various types of needs and their corresponding controls are identified, and a unified framework for closed-loop preventive and emergency control is proposed. The focus is on feasibility aspects, description of salient features and comparison of specifics, application contexts and uses.

Introduction: Power system transient stability control is an important and problematic task that conventional time-domain transient stability methods cannot handle in a systematic and efficient way. Direct methods, on the other hand, are better suited, but they lack flexibility with respect to power system modeling, stability scenarios, and types of instability. This explains why today hybrid methods are preferred to pure direct methods.

Broadly, two classes of hybrid methods may be distinguished, namely, those relying on multimachine Lyapunov functions and those using generalized one-machine equivalents. The popular TEF method is of the former class, the more recently developed SIME method belongs to the second class [1]. The framework proposed in this letter uses SIME.

Transient Stability Control, a Classification: Transient stability control in general encompasses a twofold problem: severity assessment of an instability originating from the occurrence of a “dangerous” contingency, and choice of an action able to stabilize it. The control may be of the “preventive” type or of the “emergency” type.

Preventive control aims at answering the question “what to do” in order to stabilize the system postfault operating condition if a (plausible) contingency would occur. Its design relies on stability simulations of contingency scenarios.

More precisely, *online preventive control* aims at predicting in a horizon of, say, 30 minutes ahead, means to stabilize the system if it were threatened by any of the plausible contingencies identified to be dangerous. It may be accomplished by using a load forecasting program to predict the system operating state, assessing its stability under all dangerous contingencies and finally designing appropriate control actions able to stabilize the corresponding contingency scenarios. The decision about whether to execute or postpone the resulting control actions relies on the judgement of the engineer in charge of the power system operation.

Emergency control, on the other hand, aims at triggering a control action in real time, after a dangerous contingency has actually occurred. Note that this control action may be either designed in real time using real-time measurements, or assessed in anticipation by means of offline stability simulations. The latter case belongs to *open-loop emergency control*, as opposed to *closed-loop emergency control*, where the action is designed and triggered in real-time, while system disturbance is actually taking place, and the system continues to be monitored and further controlled, if necessary. This letter deals with closed-loop preventive and emergency controls.

Brief Glance at SIME: In essence, SIME assesses the behavior of a power system in its post-fault configuration (after a disturbance inception and its clearance) in terms of a generalized one-machine-infinite-bus (OMIB) transformation [1]. This OMIB equivalent results from the aggregation of the groups of critical machines and of noncritical machines” into two equivalent machines, further replaced by a one-machine equivalent.

The identification of these two groups of machines is described below and portrayed in Figure 1. The parameters of the OMIB (rotor angle and speed; mechanical and electrical powers) are computed from the parameters of the power system machines. These latter parameters may be provided either by a step-by-step time-domain program (i.e., by numerical simulation of a stability case) or by real-time measurements, describing the actual power system evolution with time.

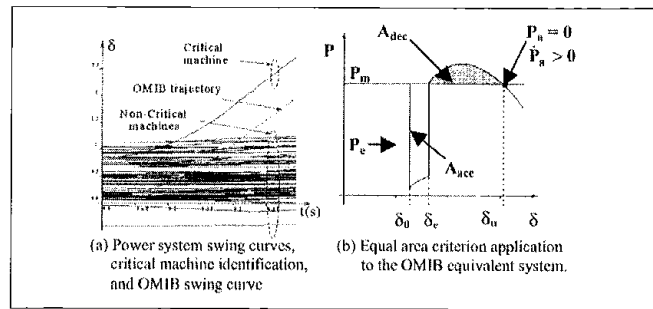


Figure 1. Illustration of SIME's principle

The use of a time-domain stability program yields the *preventive SIME*, the use of real-time measurements the *emergency SIME*. In either case, the resulting “generalized OMIB” has time-dependent parameters, refreshed at the rate of the stability program steps or of the measurements acquisition, as appropriate.

In both cases, SIME extracts two essential parameters from the “generalized” equal-area criterion (EAC), i.e., the EAC drawn for the generalized OMIB. These are: stability margins and critical machines.

The stability margin expresses the imbalance between accelerating and decelerating areas of the OMIB d-P plane (see Figure 1b). In particular, for an unstable margin this yields:

$$\eta = -\frac{1}{2} M \omega_u, \quad (1)$$

where ω_u denotes the speed the OMIB assumes at the unstable angle δ_u , this latter being reached when the OMIB accelerating power, $P_a = P_m$ (its mechanical power) - P_e (its electrical power, becomes zero, with positive derivative).

On the other hand, the critical machines correspond to the OMIB which first reaches an unstable angle δ_u . Note that the easy and unambiguous critical machines identification is essential for control.

SIME-Based Control Techniques: The control techniques furnished by SIME rely on the following two propositions. (i) A multimachine power system instability is measured by its margin (1); (ii) Stabilizing an unstable case consists of canceling out this margin, i.e. of increasing the decelerating area and/or decreasing the accelerating area of the EAC (see Figure 1b). Broadly, this may be achieved either by:

- Reducing the mechanical power of the OMIB, e.g., by using fast-valving, generator shedding, generator rescheduling, etc.
- Or by increasing the electrical power, e.g., by using braking resistors, dc links, thyristor controlled series compensators, and other FACTS.

Thus, for example, preventive control may be achieved by rescheduling active generation power among machines. Emergency control, on the other hand, which aims at protecting large production sites, like hydro plants, may call upon last resort actions, e.g., generation shedding.

Figure 2 proposes a unified organization of a closed-loop control framework, resulting from the above SIME-based principle. As can be seen, the core of the method consists of blocks 1 and 2 that are common to preventive and emergency controls. On the other hand, the specifics of these controls are identified in the right-hand and the left-hand parts of this figure (respectively for preventive and emergency control), and further commented below. In order to make the reasoning concrete, without loss of generality, the comments consider the case of generation changes (generation rescheduling for preventive control; generation shedding for emergency control).

Preventive Control: According to Figure 2, for a given stability case (contingency scenario and operating state, possibly predicted via a load forecasting function), SIME computes the (unstable) margin and identifies the critical machines. Accordingly, SIME proposes a control action necessary to cancel out this margin.

For example, when the control consists of generation rescheduling, SIME assesses the approximate amount of OMIB mechanical power change (generally a decrease), necessary to cancel out this margin, using a compensation scheme [2]. This OMIB change should be in turn reported on the system critical machines, and, whenever the purpose is

to continue matching the load, it should be compensated by a generation change of equal size and opposite sign on noncritical machines. Note that, whenever there is more than one critical machine, the generation change reallocation among them may follow various patterns (e.g., see [2]). Further, the generation reallocation on non-critical machines may comply with various objective functions (e.g., maximum power transfer on preassigned tie lines; minimum cost; ATC calculations; etc.).

Given the control action designed by SIME (e.g., generation rescheduling), a power flow is run, followed by a transient stability assessment. If the system has been stabilized and the stability margin has (nearly) become zero, the procedure stops. Otherwise, a new control cycle is performed.

In Figure 2, the closed-loop preventive SIME follows the path of blocks 1, 2, 3, 4, 1. This process converges quite rapidly, thanks to margins extra- (inter-) polations. Generally, two to three iterations are found to be sufficient. In terms of computing times, the overall process is well within online DSA requirements [2].

Emergency Control: The emergency SIME relies on real-time measurements taken at the power plants. Its main objectives are to [3]:

- Assess whether the system is stable or it is driven to instability, in the latter case
- Assess how much unstable the system is going to be, accordingly
- Assess where and how much corrective action to take (preassigned type of corrective action)
- Continue assessing whether the executed corrective action has been sufficient or whether to proceed further.

Block 1 of Figure 2 covers the prediction of (in)stability and appraisal of the size of instability. Block 2 takes care of the design of an appropriate control action. For example, when generation shedding is of concern, the action consists of determining the number of generators to shed. Further, the method sends the order of triggering the appropriate action, while continuing to monitor and control the system in closed-loop until guaranteeing power system stabilization. Figure 2 suggests that the closed-loop emergency control follows the path of blocks 1, 2, 5, 6, and back to the power system.

By comparing emergency with preventive control one may note the following essential differences:

- The control is based on real-time measurements acquired at regular time intervals and aims at controlling the system in less than, say, 500 ms after the contingency inception and its clearance.
- The prediction of instability starts after detecting an anomaly (contingency occurrence) and its clearance by means of protective relays. Note that this prediction does not imply identification of the contingency (location, type, etc.). Observe also the following:
 - The prediction is made possible thanks to the use of the OMIB transformation: predicting the behavior (accelerating power) of all of the system machines would have led to totally unreliable results.
 - The use of the OMIB makes also possible the prediction of the "time to instability"; this is important information, able to influence the control decision (size of control; time to trigger it; etc.).
 - The method itself provides criteria able to assess the reliability of its own prediction; it thus provides suggestions about when to start acting. Note also that the severer a contingency, the faster (and more accurate) the prediction.

Finally, note that the hardware requirements of the emergency control scheme are phasor measurement devices placed at the main power plant stations and communication systems to transmit (centralize-decentralize) this information. These requirements seem to be within reach of today's technology.

Discussion: The online preventive control scheme of Figure 2 may easily be adapted to the simultaneous stabilization of all dangerous contingencies, thus speeding up further online simulations. Besides, as already mentioned, it may comply with various objectives, such as: maximum allowable transfer on a preassigned corridor; available transfer capability (ATC) calculations; minimum generation cost; or combination of some of them. All these preventive control techniques rely on simulations performed with any time-domain transient stability pro-

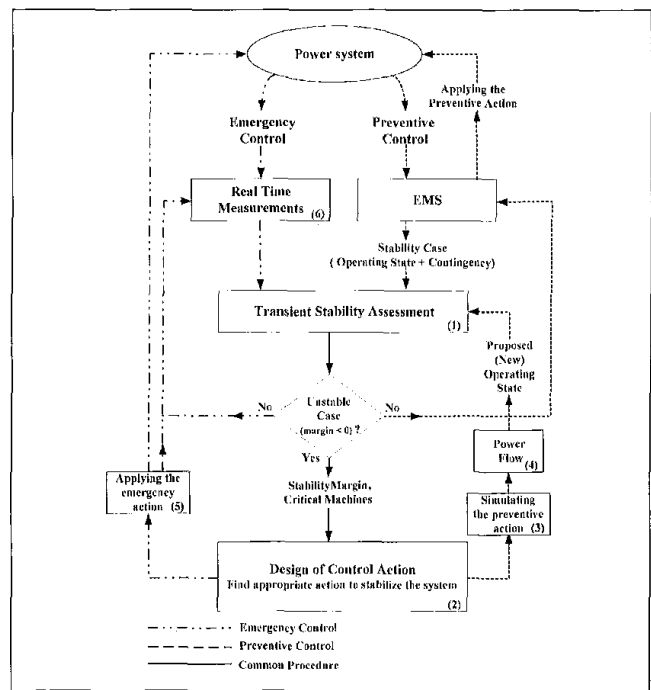


Figure 2. General framework for closed-loop transient stability control

gram (ETMSP; ST-600; EUROSTAG; ...) coupled with and driven by SIME.

On the other hand, the emergency control relies on purely real-time measurements (actually a relatively small number of measurements). This frees the control from uncertainties about power system modeling, parameter values, operating and contingency conditions. Besides, such a closed-loop emergency control is more economic than open-loop emergency control or mere preventive control.

These important advantages of emergency control make it a valuable complement to preventive control but certainly not a substitute. Indeed, it is at the junction of the two above types of control techniques that satisfactory solutions to particularly challenging operating problems could be found.

Conclusion: Direct methods gradually changed scope during more than three decades of development. Indeed, one of their primary objectives was to speed up transient stability computations and to get simulations "faster than real-time". Today, this objective is well within reach of "brute force" time-domain programs, thanks to the fantastic progress of computer performance.

Meanwhile, the secure operation of modern power systems has created needs impossible to meet by pure time-domain methods. Transient stability control is a good example. At the same time, pragmatic approaches resulting from the hybridization of direct methods became able to meet such stringent requirements. It is anticipated that the deregulation of the electric industry will contribute to speed up the effective implementation of these sorely needed new tools.

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