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Early Warning System Based On Power System Steady State and Dynamic Security Assessment

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Existing security and reliability based EMS applications (e.g. Online Dispatcher Power Flow, Online Contingency Evaluation, Online Short Circuit Calculation, etc.) normally take real time snapshot of the system and perform necessary studies to evaluate the security and reliability of the network. As these applications do not provide any information about the security level of the system for the near future, the operator in control center may not get enough time to effectively arrange for proper corrective actions in case of security criteria violation. This paper presents an online early warning system based on steady state and dynamic security assessment which looks ahead and generate proper alarm for operators in case security criteria is expected to violate in near future. The proposed system can easily be integrated with SCADA/EMS system for transmission control room application to give operator a wide view of the entire network and help him in better control and monitoring of the power grid.

Keywords: Early warning system, steady state security, dynamic security, EMS application

1. Introduction

Power systems are dynamic in nature with frequently changes in load and generation. Therefore, in order to operate power systems safely, system bottlenecks should be identified well in advance and necessary remedial actions should be provided to maintain operational limits. However, off-line studies cannot identify all possible operating conditions that may arise. Furthermore, operators have only access to the conclusions of off-line studies and they are not fully aware of detailed assumptions that might have been used during studies. Accordingly, to provide continuous, safe and reliable supply, operating conditions vulnerable to both steady state and dynamic instability should be identified well in advance. Therefore, it is desirable to anticipate dangerous system condition in real time basis and give early warning alarm to operator. This can be accomplished by integrating an early warning system with existing SCADA/EMS applications (such as State Estimator, Online Short Circuit Calculation, Online Contingency Evaluation, Load Forecast and Unit Commitment Applications, Economic Dispatch Application, etc.) to provide a full set of monitoring and control functions using advanced set of power applications, modeling techniques and solution algorithms. SCADA/EMS is hardware and software system which is used to monitor and control power system. The main purpose of SCADA is data acquisition and system monitoring and control. EMS applications are also used to look after power system security ([1], [2], [3], [4], [5], [6], [7], [8], [9], [10]). Fig.1. shows the integration of proposed early warning system with existing EMS applications.

Most of existing EMS applications (e.g. Load Flow Analysis, Contingency Evaluation, Short Circuit Calculation, Active an Reactive Power Optimization, etc.) normally take real time snapshot of the system and perform necessary studies to evaluate the security and reliability of the network and highlight the existing bottlenecks considering the current

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operating point. As these applications do not provide any information about the security and reliability of the system for the near future (e.g. next 6 hours, 10 hours, 15 hours, etc., adjustable based on user requirement), they may not effectively assist operator to find out or implement, in short period time, proper corrective or remedial actions in case of security and reliability violation. Some other look ahead EMS applications (e.g. Unit Commitment application, Economic Dispatch, etc.), work on scale of days and provide functional capabilities for the user to economically schedule system resources (generation and transactions), however, as they do not consider security and reliability of the system, the user will not be provided with any early warning alarm if system security and reliability is expected to violate in future. To take care of above mentioned issues related to the EMS applications, this paper proposes an early warning system which can be integrated with the existing EMS applications to generate proper alarm for the users in case steady state and dynamic security of the system is expected to be violated in near future (e.g. next 6 hours, 10 hours, etc., adjustable based on user requirement).

2. Structure

In real time operation, it is vital to know the existing status of power system from security point of view and anticipate it for close and near future (.e.g. for next 6 hours, 10 hours, etc., adjustable based on user requirement). This will give enough time to operator to prevent operation of the system in insecure condition and be ready with proper corrective actions.

Power system security means that in case of disturbance, the power system (1) will survive after the disturbance and go to an acceptable steady state operating point, and (2) in the new steady state operating point, no voltage violation or equipment over load will take place [11]. The first condition which is dynamic security is evaluated in time domain simulation through transient analysis and the second one which is steady state security is assessed through normal power flow and contingency analysis. The application can be equipped with suitable user interface to provide operators clear and useful information about the security of the network and critical contingencies/ equipment.

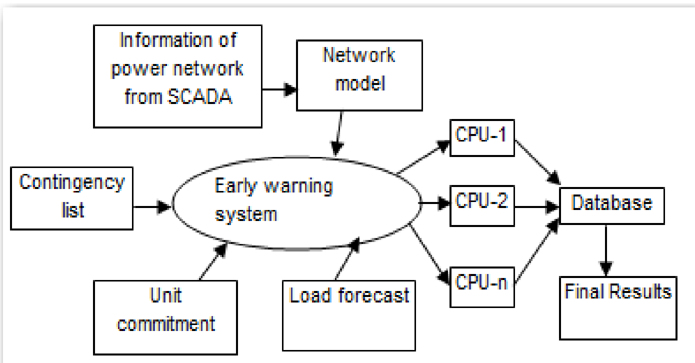

Fig.1: integration of proposed system with existing SCADA/ EMS applications

Steady state security assessment is mainly based on power flow calculation. In a secure power system during normal condition as well as post contingency, power flows and bus voltages remain within acceptable limits despite changes in load, unit commitments and status of network equipments. As the occurrence of disturbances and contingencies cannot be predicted, in this paper, N-1 contingency has been considered in proposed early warning system. Although any number of contingencies can be included in the early warning system, however, as run time for online EMS applications is restricted, only credible contingencies may be considered. For all considered contingencies, no voltage violation or equipment overload should take place for existing and near future condition (e.g. next 6 hours, 10 hours, etc. adjustable based on user requirement).

Dynamic security assessment is mainly evaluated considering critical fault clearing time (CFCT) and time delay of protection relays. If calculated CFCT is shorter than operating time of relay equipments, then system will lose its synchronism and accordingly, some precautions such as adjusting generation and unit commitment will be required. However, our objective in online early warning system is not precise calculation of CFCT but is to identify that if system stability can be preserved for extended faults (i.e. faults cleared with backup protection). As operating time for backup protections is mainly related to voltage level and will be uniformly selected for the network (e.g. 300ms for the network), it is only required to examine the system stability for faults with duration of e.g. 300ms. If for existing or near future operating point (e.g. next 6 hours, 10 hours, adjustable based on user requirement) a fault with the duration of 300ms (time delay for backup protection) causes some machines going out of synchronism, critical system load, machines and fault locations will be reported through early warning system. In this case, operator will have enough time to arrange for corrective or remedial actions (such as change in unit commitment, operating generators in more lagging power factor, etc.) in advance and avoid operating the system in insecure state.

It is important to underline that although early warning system can consider any type of faults, fault locations, fault durations, and etc., it is sufficient to evaluate the security of the system for a three phase fault (with time delay of backup protection, e.g. 300ms) on high voltage side of generators. This is because if system maintains its synchronism for a three phase fault at the nearest bus to generators, it will preserve its stability for other types of fault at remote buses with more distance from generators. Considering this point will significantly reduce computational time.

3. Approaches

For the purpose of early warning system, following procedure which is based on steady state and dynamic security assessment is proposed.

3.1. Early Warning System Based on Steady State Security Assessment

The algorithm for early warning system based on steady state security assessment for e.g. next 6 hours which is shown in Fig.2 is described below:

a) Start with the existing network condition and operating point.
b) Run the load flow.
c) Monitor power flow of equipments and voltage of bus bars.
d) If there is overload condition or voltage violation, go to step J.
e) Run contingency analysis (e.g. N-1, or according to list of credible contingencies).
f) Monitor flow of equipments and voltage of bus bars.

g) If there is overload condition or voltage violation, go to step J.
h) Obtain system load for next hour from the load forecast module and distribute it at each load bus as per expected load trend (k=1 corresponds to system condition after one hour from the existing operating time, k=2 after 2 hours, etc.).
i) Obtain generation pattern from unit commitment module for next hour and update the existing generator's MW, then go to step b.
j) Identify critical system load, critical contingencies, etc, and search for proper corrective actions.

It should be noted that steady state security violation (over load condition or voltage violation) will normally take place much before reaching critical/ knee point on PV curve. Moreover, change in system load within next e.g. 6 hours is limited and is much lower than the system load corresponding to critical point. Therefore computational time for steady state security assessment is considerably lesser than finding critical point or steady state voltage stability margin. In addition to that, using parallel processing by multiple processors, it is possible to reduce processing and computational time.

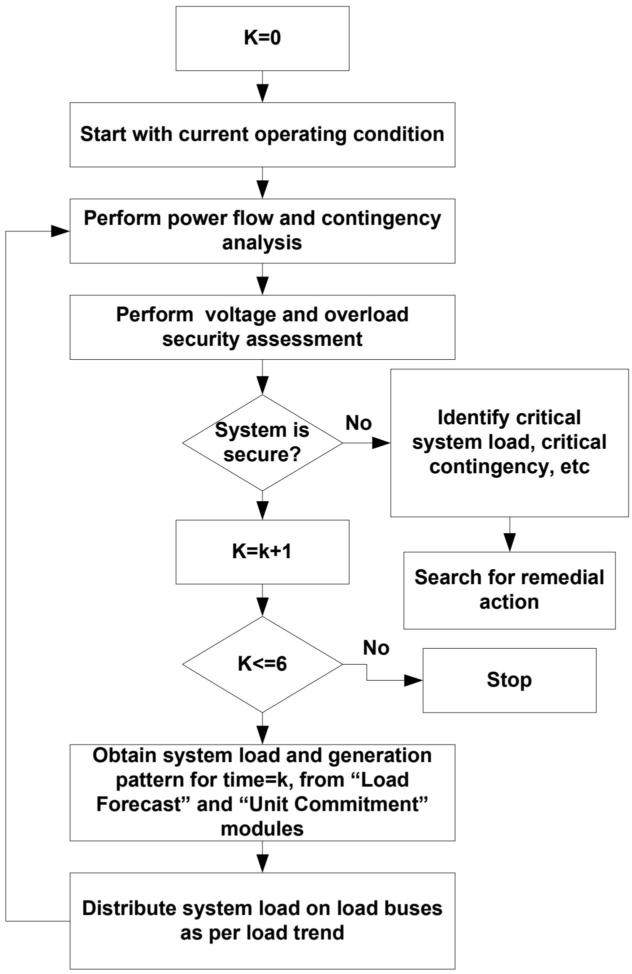

Fig.2: structure of early warning system based on steady state security assessment

3.2. Early warning System Based on Dynamic Security Assessment

The algorithm for early warning system based on dynamic security assessment for e.g. next 6 hours is shown in Fig.3 and is described below:

a) Start with the existing network condition and operating point.
b) Perform dynamic simulation for extended three phase and/ or single phase fault on HV bus of transformers connecting online generators to the network (called generator transformer).
c) If any machine goes out of synchronism, then, go to step f.
d) Obtain system load for next hour from the load forecast module and distribute it at each load bus as per expected load trend (k=1 corresponds to system condition after one hour from the existing operating time, k=2 after 2 hours, etc.).
e) Obtain generation pattern from unit commitment module for next hour and update the existing generator's MW, then go to step b.
f) Identify critical system load, critical machines, etc, and search for proper corrective actions.

Early warning system gets some of inputs from Load forecast, unit commitment and economic dispatch modules which are basic look-ahead functions of EMS. Load forecast module provides expected load for next days (in 15 minutes, half an hour, or hourly basis) and the task of unit commitment and economic dispatch is deciding when and which generating units at each power station to start-up and shut-down and what should be individual power outputs of the scheduled generating units at each time-point. This information is also available for next few days in 15 minutes, half an hour, or hourly basis.

It should be noted that calculating CFCT for each and every bus for different types of fault in time domain simulation is a time consuming process, however, in early warning system, we are not going to calculate CFCT for different fault type. Early warning system will assess system stability only for fault (with fixed fault duration) on HV side of generator transformer. The fault can be normal or extended three phase and/ or single phase fault (i.e. fault cleared by main or backup protection). If it is decided to check system stability for three phase fault, system stability for single phase fault can be ignored because three phase fault is the worst one among different fault types. Moreover, all machines at a particular power station normally connected to the same HV bus through different generator transformer. Accordingly, scenarios (i.e. fault locations, fault types and fault duration) which should be considered in early warning system will be limited, and processing time for dynamic security assessment will considerably less compare to calculating CFCT for different buses.

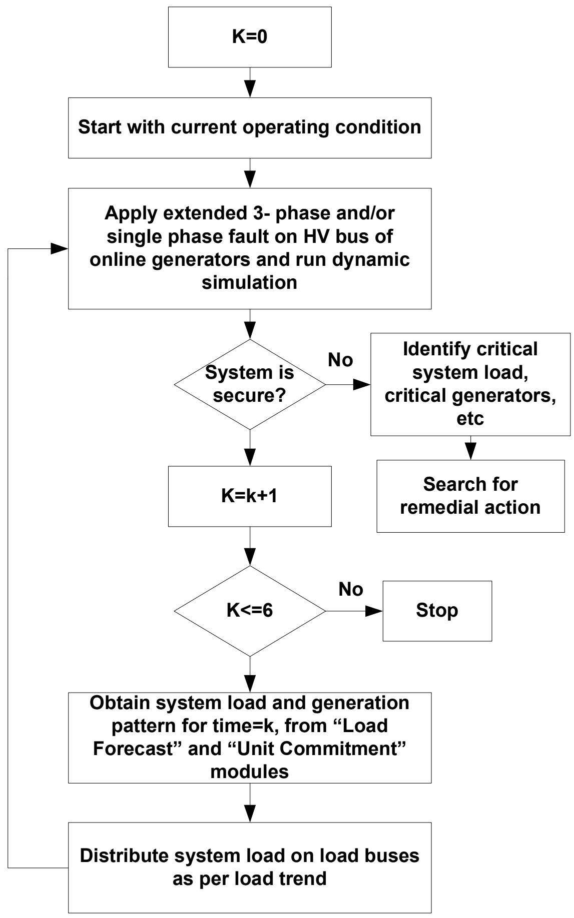

Fig.3: structure of early warning system based on dynamic security assessment

4. Corrective Actions

In case operators observed that steady state security is expected to be violated in near future, violations can be fixed using different methods such as: shunt capacitors and reactors, changing generation dispatch, islanding, OLTC and etc.

Operator can enhance dynamic security by operating critical generation units in more lagging power factor, or by decreasing active power of critical machines.

5. System Architecture

The early warning system consists of three parts. The first part is user interface which enables users to select the operation mode (e.g. cyclic, spontaneous, manual, etc.), study period (e.g. 6 hours, 10 hours, etc.). In addition, users may define other parameters such as contingency list (e.g. all N-1 contingency, ranked contingency, user defined contingency, etc.), load increase direction, fault types and locations, fault duration and through user interface.

The second part is calculation engine which processes the input data and produce outputs. As the proposed early warning system is based on steady state and dynamic security assessment, its calculation engine includes both power flow and transient stability analysis.

Visualization is the third part of the system which provides users with meaningful information and results such as critical system load, critical contingencies, critical machines, critical fault locations, etc. As the main focus of the paper is the algorithm and methodology of the proposed early warning system, the visualization part is beyond the scope of this paper and can be customized according to the user specific requirement.

6. Results

Results of testing the proposed early warning system on a model retrieved from the energy management system of a real power network are described below. The system under study includes 60 generators and consists of, in addition to the generator buses, 400kV (10 buses), 230kV (5 buses), 132kV (101 buses), 63kV (68 buses) and 20kV (149 buses) voltage level. Number of 400kV, 230kV, 132kV and 63kV circuits is 29, 9, 160 and 87 circuits respectively.

After successful execution of state estimator, a snapshot file in PSS/E format was created. This file along with dynamic data file for generators and their controllers were used as input data to early warning system.

A shell was developed to feed the software with unit commitment, system load, substation load trend and etc. for next 6 hours, i.e. the study period was considered to be 6 hours and the system was set to run every 30 minutes in cyclic mode.

Table-1 shows MW output of each power station for next 6 hours from the reference time. Summary results of early warning system based on steady state security assessment (considering N-1 contingency) are shown in Table-2. From Table-2 it is clear that at 13:00hrs, tripping of L4001-4002 circuit will cause overloading of L4003-4004 circuit. Also at 14:30hrs, tripping of L1321-1322 circuit will cause overloading of L1323-1324 circuit.

Summary results of early warning system based on dynamic security assessment (considering 300ms for single phase fault and 100ms for three phase fault, however, the fault duration is editable by the user) are shown in Table-3. From Table-2 it is observed that at 14:00hrs, three phase fault on bus B4006 will cause one unit PS6-1 will loose its synchronism.

Table-1: MW output of power stations from 09:00hrs (reference time) for next 6 hours

Time	PS1 (MW)	PS2 (MW)	PS3 (MW)	PS4 (MW)	PS5 (MW)	PS6 (MW)	PS7 (MW)	PS8 (MW)	PS9 (MW)	PS10 (MW)	Gen Total (MW)
09:00	231	567	435	381	92	885	0	1921	300	1158	5969
09:30	231	563	480	382	143	880	0	1950	282	1225	6137
10:00	231	562	509	382	188	877	0	1908	298	1287	6242
10:30	231	564	548	381	256	871	0	1878	336	1269	6334
11:00	231	564	547	379	259	872	0	1891	399	1254	6396
11:30	232	565	551	376	225	872	0	1917	321	1327	6384
12:00	232	564	567	377	227	872	0	1910	428	1245	6422

12:30	256	565	567	379	338	872	0	1945	400	1159	6482
13:00	273	565	568	380	252	872	0	1889	351	1352	6501
13:30	288	564	568	379	358	872	0	1951	419	1162	6562
14:00	287	564	569	378	381	872	0	1923	419	1208	6601
14:30	288	567	570	379	436	873	0	1940	427	1148	6627
15:00	288	566	568	378	439	875	0	1933	434	1148	6629

Table-2: results of early warning system based on steady state security assessment

Sr. No.	Time	Critical System Load (MW)	Critical Circuit	Overloaded circuit
1	13:00	6501	L4001-4002	L4003-4004
2	14:30	6627	L1321-1322	L1323-1324

Table-3: results of early warning system based on dynamic security assessment

Sr. No.	Time	Critical System Load (MW)	Fault type	Fault duration	Critical location	Critical machines
1	14:30	6627	3 phase	100ms	B4006	PS6-1

7. Conclusion

In this paper an early warning system based on steady state and dynamic security assessment was proposed. The main difference between the proposed approach and existing EMS applications is that the existing EMS applications assess the security and reliability criteria associated with the current operating condition without providing information about expected bottlenecks in near future. However, the proposed early warning system looks ahead and generate proper alarm incase violation of security and reliability criteria is expected in near future. The proposed system can easily be integrated with existing SCADA/EMS applications as a real time tool to enable operators to arrange for preventive and remedial actions well in advance before power system moves to alert states.

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