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Real-time Online Dynamic Security Assessment using Phasor Measurement and Load Forecast

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SUMMARY

This paper describes a novel two-stage online dynamic security assessment (DSA) scheme that uses phasor measurement and load forecasting data. The scheme determines the steady state stability and identifies endangerments of the system in real-time. The procedure will periodically examine system status and predict system endangerments in the near future every 30 minutes. System real-time operation conditions will be determined by state estimation using phasor measurement data. The assessment of transient stability is carried out by running time domain simulation using a forecasted working point as the initial condition. The forecasted operation condition is calculated by DC optimal power flow (DC-OPF) based on forecasted load data.

Online DSA analysis has been developed and applied in several power dispatching control centers. Existing applications of traditional DSA are limited by the assumption of system operation conditions and computational speeds. To overcome these obstacles, this paper proposes a novel two-stage DSA scheme to provide periodical system security prediction in real time. The major contribution of the proposed method lies on the incorporation of PMU data and forecasted load in the DSA system. The ahead-of-time prediction of the system has the ability to provide more accurate assessment of the system and minimize the disadvantage of the low computational speed of time domain simulation.

The proposed scheme is simulated on the IEEE 118-bus test system, which consists of 19 generators. The test results show that the proposed two-stage DSA scheme is able to predict potential endangerments of the system for the working point in the near future, online. The proactive prediction is of vital importance, especially when the power system is experiencing increasing loading during the period of a day.

KEYWORDS

Online Dynamic Security Assessment, Phasor Measurement, Transient Stability, Steady State Stability, Predication, Load Forecast, 118 bus system.

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I. INTRODUCTION

Power system security is one of the basic functional aspects of power system reliability, which means "the ability of the bulk power electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system components". This definition for the term power system security is given by the North American Reliability Council (NERC) and widely accepted in North America. "Dynamic Security Assessment" (DSA) is one part of the security analysis, which determines the transient stability of the system [1].

The study of online DSA has been brought into focus lately, because of the heavy load operating condition and the increasing complication of components and configuration in power systems. Furthermore, phasor measurement units (PMUs) are available to provide accurate relative phase angle on the precision of 0.02 electrical degrees and to calculate phasor components for a wide area system. With the development of PMUs, several approaches have been developed for transient stability analysis, including numerical integration [2], energy function method [3], direct method of Lyapunov [4], decision trees [5], pattern recognition [6], dynamic state estimation [7], and probabilistic methods [8].

A majority of past research focuses on post-fault transient stability analysis, while little focus is placed on pre-fault analysis of the future network conditions.

A DSA with pre-fault prediction [9] is able to alert operators to the potential risk before the system experiences a fault or lightning strike, so that operators are able to take preventive actions to improve reliability. [10] and [11] point out that DSA with pre-fault prediction should be performed on both the current working point and the working points of the near future. Very little work has been done on developing real-time periodically DSA systems that incorporate load forecast.

This paper presents a novel two-stage DSA scheme to provide comprehensive and proactive online analysis in real time. Section II illustrates the proposed computational frame work for the two-stage DSA scheme. Section III introduces the methodologies implied in this new scheme. An application of the two-stage scheme using IEEE 118 bus system is described in section IV. The paper will be summarized in section V.

II. PROPOSED COMPUTATIONAL FRAMEWORK

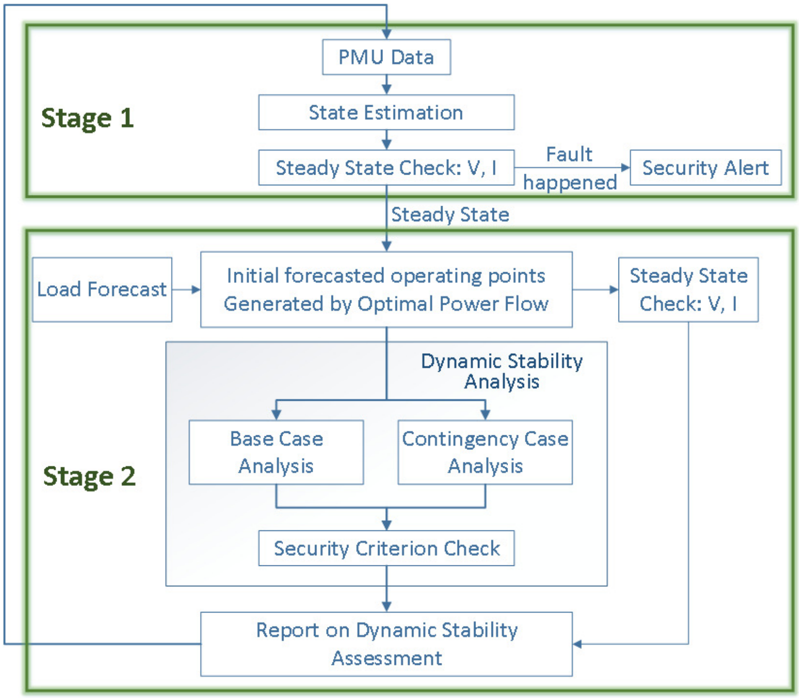

Figure 1. Computational framework of the two-stage DSA scheme

The proposed DSA scheme contains two stages as shown in figure 1. The first stage checks system operating conditions in real time using state estimation with PMU data. A steady state operating condition will trigger the second stage of the proposed DSA system to examine dynamic security in the near future.

Stage 1

Power systems operate under the presence of disturbances, so simply assuming steady-state operating conditions will introduce large prediction errors and may cause DSA failure. Therefore, a new stage is added to the traditional DSA scheme to determine whether the system is in steady state operating condition or not. If the system is in steady state, the scheme will check voltage limits, thermal limits, and power output limits of generators. Alert signals will be sent when violations are detected for the above limits. The response to the operating condition under disturbances is currently under development.

Stage 2

The second stage is the main part of the DSA system, which will be performed only after the system is determined as steady state operating condition within limitations in stage one.

Instead of using the current operating point as in traditional DSA systems, a forecasted working point of the system is calculated and applied to perform real-time DSA. For example, assume the current operating point is a, and the predicted operating point in the near future (prediction period, 30 minutes) is b. In the proposed scheme, the assessment of the dynamic security will be performed based on operating point b instead of a. By doing this, the DSA system can get assessment results of operating point b at the operating point b, if the simulation time is equal to or less than the prediction period.

Fairly exact short-term load forecast is available in the database, benefited from the development of weather forecasts and artificial intelligence techniques. According to [12], it's relatively easy to get forecasts with about 10% mean absolute percent error. Based on the forecasted load, DC optimal power flow is performed to calculate system states with the optimal dispatch of the generation. The calculated states are trusted as forecasted operation points of the system. Then with time domain simulation (TDS) for transient stability, the DSA system determines whether the pre-fault working point is secure or not. Numerical integration is the technique to perform TDS. During TDS, a list of contingencies will be added to the system to calculate accurate generator rotor angle after disturbances. Although the integration process of time domain simulation is time-consuming, the usage of the forecasted operating point has the capability to surmount this disadvantage. Because the prediction period between current working point and forecasted working point provides enough time to simulate and analyze the critical contingencies within DSA systems.

The two-stage DSA system generates a security report at the end of an assessment cycle. A full DSA assessment cycle is determined by load forecast period, and is typically about 30 minutes to 1 hour.

III. METHODOLOGY

1. Current Operating Point Obtained from State Estimation with PMU Data

State estimation calculates an optimal estimate of the power system states using redundant measurements. The measurements in the proposed scheme are the current and voltage phasors from PMU. It is assumed that enough PMUs with enough channels are installed in the system, and that PMUs record bus voltage phasors at associated busses and current phasors along all branches that are incident on the associated bus. The scheme performs weighted least square state estimation incorporated with PMU data as the first step of DSA system.

2. Load Forecast

The load demand data used in this paper is the national demand for the Great Britain and State demand of the New York State during July 2015 [13].

Using Forecasted load data for DSA is able to provide more accurate prediction results for the system in the near future. Figure. 2 is a comparison between the half hourly load demand of current operating points and the predicted load profile of predicted working points.

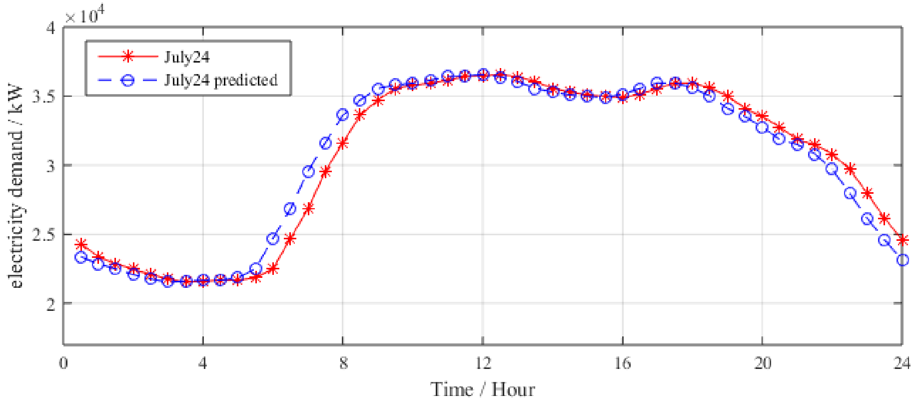

Figure 2. National demand and forecasted half-hour-ahead electricity load of the Great Britain on July 24, 2015

In Figure 2, the solid line represents loads at the current working points, while the dashed line is the forecasted load predicting the future loads for the next half hour. The difference between current load and the forecasted load is the expected load change in the next half hour. The maximum load change occurred between 7 am and 7:30 am, which is 9.25% of the load at 7:30 am. The average maximum value of the load change through July is 8.94%.

The differences between the two curves can be observed in most of the load types as shown in Table 1. According to Table 1, although different load types have different characteristics, hourly loads will vary from 5% to 20% in general. Because of the existence of the difference, a DSA system based on current working points will cause errors in transient stability simulation depending on the certain load type.

Table 1 Difference between utilized load and forecasted load of New York State during July 2015

Load Type		Average Maximum difference	Peak hours	Average Maximum difference during peak hours
Standard Service		14%	19 - 20	4%
Standard Optional Large Time of Use		14%	16 - 20	6%
Commercial/industrial customers (monthly measured demand < 100kW)	Not greater than 2,000 kWh in each month for four consecutive months	35%	11 - 17	13%
	Greater than 2,000 kwh in each month for four consecutive months	14%	12 - 17	8%
Commercial/Industrial Customers (Monthly Measured Demand Exceeds 100kw In Each Of The Previous 12 Consecutive Months)	Secondary customers (<2.2kV)	23%	14	3%
	Primary customers (2.2-15 kV)	10%	9 - 15	10%
	Sub-transmission Customers (22-50 kV)	12%	12 - 16	7%
	Transmission customers (>60 kV)	16%	8 - 15	6%
Lighting		6100%	1–5; 22-24	100%

The proposed scheme takes consideration of the load change in the next half hour, and reduces simulation error by incorporating the half hourly forecasted load in DSA systems. Therefore, the proposed DSA system is able to provide more accurate dynamic security assessment.

3. DC Optimal Power Flow

The forecasted load cannot be used directly to present forecasted system status because the forecasted working points depend on both forecasted load and forecasted generator dispatch. The short term forecasted loads are available from load forecasting companies, while the power generator dispatch is determined mainly by electricity demand and operating cost.

Generation dispatch problems can be solved by optimal power flow (OPF) which provides economic dispatch solution and simultaneously calculates power flow of the system. Instead of AC OPF, DC OPF is performed in the DSA scheme to avoid non-linear or non-convex problems. The forecasted load is used in DC OPF to obtain the forecasted generator dispatch. The results of DC OPF are trusted as forecasted operation points of the system.

4. Security Criterion

The scheme examines thermal and voltage limits of the system at the end of stage 1. If no violation occurs, the program will get into stage 2. Otherwise, the program will generate an alert.

The angle of instability is determined in stage 2. Define $\Delta\delta$ as the difference between generators' rotor angles and the center of angles (COA) of a region. The threshold commonly used to check $\Delta\delta$ for stability is 60 degrees for accelerating conditions and -65 degrees for decelerating conditions [6].

DSA reports will be supplied to operators in control centers. Operators will make judgments on endangerment of the system based on the DSA report and the acknowledgment of locations of the insecurity cases.

IV. CASE STUDIES AND SIMULATION RESULTS

The proposed scheme is demonstrated using the IEEE 118 bus test system with 19 generators. The 118 bus system has a lot of voltage control devices and is quite robotic for voltage stability. All of the generators, exciters, and governors are modeled in detail based on [14].

The realization of the proposed two-stage DSA system is based on Python Programming Language on the Windows 7 platform. The main program calls functions coded in MATLAB to calculate optimal PMU placement, state estimation, and DC optimal power flow. The MATLAB codes are on the basis of the simulation tool, MATPOWER. The main program will call TSAT to run the transient simulation, retrieve simulation data, check rotor angle margin and prepare security reports.

The half hourly power flow data of a day is generated based on the power flow data of the standard IEEE 118 bus test system. The standard case data is archived in the Illinois Center for a Smarter Electric Grid (ICSEG). The load of the standard system is scaled by load factors to imitate the load profile of July 24th as shown in Figure. 2. The load factor 1 corresponds to the 25 MW demand in Figure 2. Assume that there is no error in the half hourly forecasted load data.

Two types of contingencies are added to the system. The first type is one three phase bus fault on each bus with a clearing time of 5 cycles. The other type is one three-phase fault on each transmission line 5% electrical distance away from the bus. Each line will be examined twice because both of the two buses connected to that line could be the near end bus. The near end bus breaker clears the three phase fault at five cycles. After one additional cycle, the far end bus breaker clears the fault. The simulation time for each contingency is set as 10 seconds. It takes the two-stage DSA system around 5 minutes on average to assess the 118 bus system with 485 contingencies. The DSA system generates an alert for unsecured cases and exports the corresponding plots into documents for operators' reference.

Figure 3 shows the bus voltages of the 118 bus system at 7:30 am and the forecasted bus voltage for 8:00 am. It shows that the voltage magnitude of the system for the current working point is -0.011% to 0.49% higher than that for the forecasted working point. The system will experience slightly voltage drop from 7:30 am to 8 am.

Figure 4 illustrates an endangerment of the system predicted by the proposed dynamic security assessment system. As shown in Figure 4, two generators will lose synchronous at 8 am if a three phase fault occurs at 5% percent of the line from bus 17 to bus 18. The assessment process starts at 7:30 am and initializes the transient stability simulation using the forecasted working point of 8:00 am. The load scale factor for the forecasted load at 8 am is 1.4. Note that the shown endangerment will not be predicted if the load factor is 1.3 which is the load factor for the working point at 7:30 am. It means that the endangerment will not be predicted by traditional DSA systems on time.

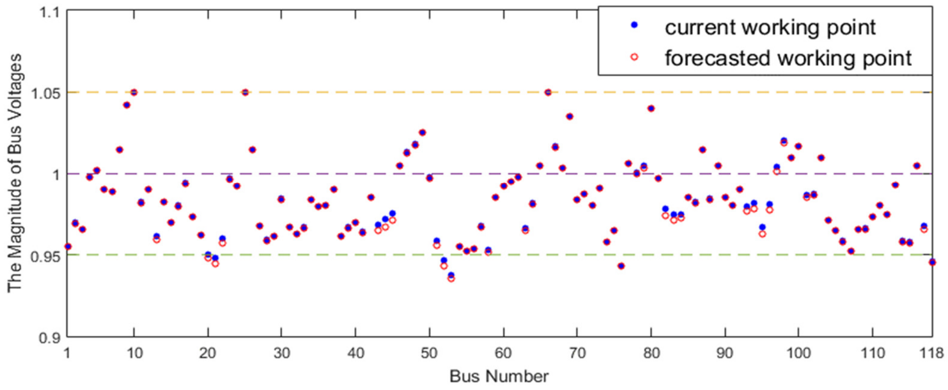

Figure 3. Graph of bus voltage for current working point and forecasted working point.

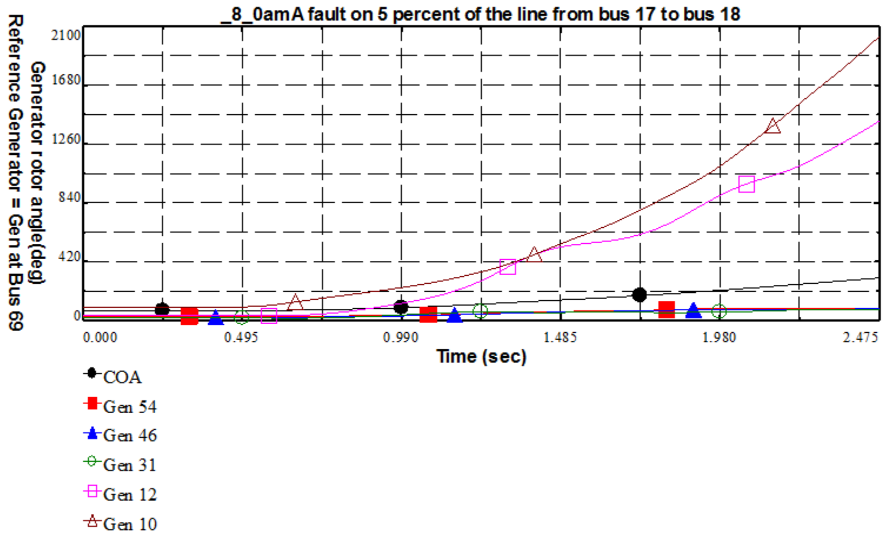

Figure 4 Insecurity identified by DSA system using forecasted load data

Table 2 Endangerment alert for DSA system with/without load forecast

Assessment Time	7:30 am		12 pm		6:30 pm	
DSA system	Without	With	Without	With	Without	With
Load Scale Factor	1.3	1.4	1.45	1.45	1.45	1.4
No. of buses with voltage below 0.95 p.u.	5	6	6	6	6	6
No. of cases unsecured	17	18	38	38	38	18

Table 2 lists different prediction results from the proposed DSA system with load forecast and DSA systems without load forecast. Three load patterns are captured in Table 2, including increase, maintenance, and decrease. The proposed DSA system is more accurate than DSA systems without load forecast especially when the system experiences load changes. The new system takes consideration of system changes in advance. As a result, it predicts more endangerments at 7:30 am and fewer endangerments at 6:30 pm.

It is important for a DSA system to have the ability to predict as many risks as it might occur. With the information of the potential risk and its possibilities, operators are able to take proper action to prevent cascading events. However, generate alerts for the impossible event is uneconomical. For example, traditional DSA systems use operating point at 6:30 pm to predict endangerment at 7 pm. Although the load decreases by only 5 % of the standard load, the number of unsecured cases reduced up to 52.6%. The misleading prediction can increase the operating cost.

V. CONCLUSION

This paper presents a two-stage DSA scheme for online dynamic security assessment. Instead of using power flow of current working points, we use PMU data and forecasted load data to examine system endangerments. The relationship between forecasted load and the forecasted working point is developed. The forecasted working point is used in time-domain transient stability simulation. The system is tested on an 118-bus system. Case study results show that the new scheme is able to provide more accurate assessment results than traditional DSA systems. Using the proposed scheme, the prediction accuracy rises to 6% for the period of load increasing, and 52.6% for the period of load decreasing.

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