

AUTOMATED VOLTAGE STABILITY PROTECTION AND CONTROL USING A WIDE AREA NETWORK OF PHASOR MEASUREMENTS

Nnadi Damian B.N

Department of Electrical Engineering
University of Nigeria Nsukka.

Abstract

When a major power system disturbance occurs, protection and control systems have to limit the impact, stop the degradation and restore the system to a normal state by appropriate remedial actions. Wide area measurement and protection systems limit the severity of disturbances by early recognition as well as proposition and execution of coordinated stabilizing actions. These systems complement classical protection and SCADA/EMS applications. This paper proposes for Power Holding Company Nigeria (PHCN), a system design based on phasor measurement units, encouraging system protection schemes for frequency, small signal angle and voltage instability. The system is compared to classical protection and SCADA/EMS systems showing its benefits. A new algorithm for long-term voltage stability prediction is introduced using the proposed system setup.

Keywords: Wide area protection voltage stability, voltage control, system protection schemes, wide area measurements, phasor measurement units.

1. Introduction

Electric utilities in Nigeria undergoing a period of fundamental change with respect in privatization deregulation and due to competition, they aim to improve economic efficiency. A free and reliable access to the electric power system is a backbone for society, industry and in particular for the electric power market activities. One of the most important results of this trend is a demand for increased utilization of assets for generation transmission and distribution in order to enhance profitability, increase owner value and minimize costs for consumers.

Practically, system wise instabilities or collapses occur frequently in many power systems [1]. Increasing transmission demands caused by the market activities are also stressing systems more and more. This leads to a lack of transmission capacity coupled with a reduced reliability. In view of all these, one of the recent achievements are wide area protection systems, which supervise the network stability and take remedial actions to prevent critical situations. Therefore, power system can be operated more closely to the stability limits. Also wide area and measurement systems [2] provide the opportunity to either

- Increase the power transmission capacity,
- Increase the system reliability, or
- Increase both in combination.

A wide area protection system does for sure not increase the physical transmission capacity but is able to increase the useable capacity. The operation strategy can be modified in the direction of higher used capacity with simultaneously reducing the risks of evolving collapses using a wide area protection system. The value of the

transmission capacity must be compared to the costs of probably taken remedial actions.

2. Requirements for a Wide Area Protection System

Maintaining a high degree on power supply reliability is essential for each utility to achieve its targets. Thus, events leading to outages in power systems have to be avoided by all means. The following major concerns are faced by power utilities, which could lead to enormous disturbances in power supply.

- Black-outs
- Voltage collapses
- Cascade tripping

Having a look at the reason behind these phenomena, it becomes obviously that they are mainly caused by wide area disturbances, such as voltage instability, frequency instability etc. [1]. Wide area disturbances could appear solely or together, everywhere in power systems and at any time. The only way to prevent or mitigate consequences of such disturbances is to monitor the dynamics of the network based on real time data and to issue combined remedial actions in due time. The operator shall monitor the identifications together with the actions and the actions shall be taken as said earlier, dependent on the period of the event automatically. Wide area protection applications must distinguish between the following physical phenomena:

- Small signal angle instability (damping).
- Frequency instability
- Short-term voltage instability
- Long-term voltage instability.

The control and protection scheme of power systems comprises mainly two types of

systems, which are working independently in most of the cases. On the one hand, there is the local protection equipment, which is acting locally to protect individual equipment such as transformers, generators, transmission line sets. The protection equipment is designed to isolate individual equipment within milliseconds in certain cases. It is acting very dynamically but without any on-line co-ordination with other protection equipment as well as with network management systems.

On the other hand, the second system deployed in nowadays power system is SCADA/EMS. "Supervisory control and data acquisition/Energy management system" (SCADA/EMS) is a network control and management system acting network-wide utilizing static or quasi-static view of power system. Thus, long-term non-dynamic phenomena happening in power systems can be handled by such systems only. Due to its data, acquisition and structure SCADA/EMS systems can operate coordinated with other systems and equipment but they are not able to take any kinds of dynamics either control actions or oscillations into account. The wide area protection system utilizes synchronized phasors measured accurately through out the network to create a precise dynamic view of power systems. This enables early recognitions of instabilities and subsequent initiation of suitable actions to maintain power system integrity. These drawbacks define the major requirements for wide area protection systems:

- Dynamic measurement and representation of events
- Wide area system view
- Coordinated and optimized stabilizing actions.
- Handling of cascaded outages.

3. Design Of A Wide Area Protection System

The wide area platform for protection, control and optimization comprises of handwork.

- Phasor measurement units (PMU)
- Communications links
- Central unit-personal computer and software.
- Data pre processing package
- Basic services
- Specific individual applications
- Graphical user interface
- Package containing model/data of the supervised power system and coordination with other software packages.

The bases for a wide area protection system are PMUs, which fulfill the requirement of a dynamic system view [3]. PMUs are placed in the substations to allow observation of a critical part of the supervised power system under any

operation conditions (network islanding, outages of lines, generators etc), taking into account certain degree of redundancy to provide sufficient data also in a case of unavailability of some data (PMU outage, communication failure etc) [4]. They measure time-synchronized voltage and current phasors, therefore directly comparable measurement are taken as snapshots [5]. Measured data were sent via dedicated communication channels links to a system protection center (SPC). Nevertheless, PMU functionality is embedded in local devices, called system protection terminals (SPT), which are able to run certain local algorithms and communicate directly with remote devices and systems like other SPT, substation automation and control or protection centers.

The SPC is a central computational unit where the collected measurements are synchronized and sorted, yielding the snapshot of the power system state. The snapshot is then processed by the Basic Services package (BS), which is part of the SPC. Applications, which were attached to the output of BS, address various phenomena occurring in power systems such as frequency and voltage instability etc. They predict the state of the power system and trigger appropriate actions if an incipient instability is detected. An ergonomic Graphical User Interface (GUI) displays their outputs as well as the output of BS to the power system operator. The structure described above is illustrated in fig. 1 below.

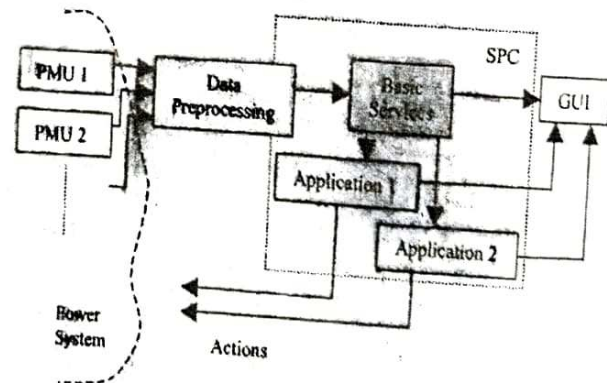


Fig 1. General setup of the Wide-Area-protection control and optimization system

3.1 Basic Services (BS)

Basic Services denote the set of algorithms included in all installations of the wide area platform for different applications and they comprise the following capabilities:

- Ability to provide needed data for any application,
- Fast execution-leaving sufficient time for running of applications within the sampling interval.
- Robustness-resistance against poor quality of some input data

(unavailability, out of range, synchronization problems etc).

These are the criterions, which have to be considered within the BS structure and its functional blocks. Some functions are triggered by event e.g. contingency whereas the majority is executed for each snapshot. The principle scheme of data flow within BS is shown in figure 2.

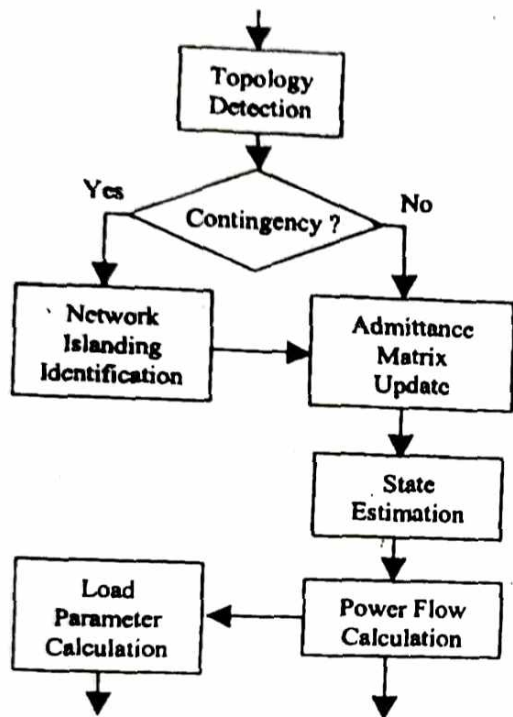


Fig.1 Structure of Basic Service

The core part of BS is the state Estimation [6]. However, as a pre-requisite, the topology of the power system and its admittance matrix representation must be known. Assuming additive error V , vector of measurements Z can be expressed

$$Z = h(x) + v \quad (1)$$

Since our phasor measurements are synchronized, the linear relationship between voltages (representing the state of the system x) and branch currents can be used to rewrite equation (1)

$$Z = H \cdot x + v \quad (2)$$

Applying weighted least squares algorithm and introducing equality constraints in order to increase accuracy of computation, [7], the optimization to be solved can be formulated

$$\text{Min, } f(x) = \frac{1}{2} (Z - H \cdot x)^T W (Z - H \cdot x) \quad (3)$$

$$\text{Subject to } C \cdot x = 0$$

Where W denotes the inverted covariance matrix, C is reduced admittance matrix so $C \cdot x$ represents the sum of currents in nodes with zero external injection.

Then the solution with long-range multipliers λ can be obtained solving

$$\begin{bmatrix} H^T W H & C^T \\ C & O \end{bmatrix} \begin{bmatrix} X \\ \lambda \end{bmatrix} = \begin{bmatrix} H^T W Z \\ O \end{bmatrix} \quad (5)$$

4.0 Mathematical Analysis

4.1 Coarse Tuning "Rotor Angle" Trajectory Building

Tractor angular position is represented by the λ and the rotor angle is represented by δ , objectives function, is given by:

$$\text{Mm } [I_f = p(w-v) + \delta [(wx-vx)^2 + (wy-vy)^2]^3 \quad (6)$$

Where T_f is a rough estimate of the final prediction time obtained from the following equation.

$$\lambda - \delta + T_f(v-w) = 0 \quad (7)$$

ζ and δ are weighting functions w, v are the rotor and predictor velocities respectively.

$$\lambda_x = \cos(\lambda), \quad \delta_x = \cos(\delta)$$

$$\lambda_y = \sin(\lambda), \quad \delta_y = \sin(\delta)$$

Differentiating and putting the equation equals to zero obtain the minimum of the objective function. A third order differential equation will result, and solving for v_y , gives

$$\partial_1 V^3 y + \partial_2 V^2 y + \partial_3 V y + \partial_u = 0 \quad (8)$$

The x-component of v is given by

$$V_x = w_x + \left(\frac{\lambda_x - \delta_x}{\lambda_y - \delta_y} \right) (V_y - w_y) \quad (9)$$

If $|\delta - \lambda| \leq T_{OL}$, switch to the fine-tuning.

5 Conclusion

The utilization of power transmission systems is limited by several stability boundaries. With the economic pressure to stress the system to a maximum, the risk of contingencies or even collapses increases. The risk of instability can drastically be reduced by the addition of a wide area control, protection and optimization system to the nowadays-common SCADA/EMS and classical protection system are a dynamic wide area view of a critical area as base for stability assessment and determination of remedial actions. The proposed approach bases only on time synchronized phasor measurement units, which allow a dynamic view of the system. The general setup of the proposed system allows implementing applications in both a

distributed local and a centralized way dependent on the availability of communication channels and special needs of the application.

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