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Survey on Priorities and Communication Requirements for PMU-based Applications in the Nordic Region

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***Abstract*—Phasor based Wide Area Monitoring and Control Systems (WAMC) promise to offer more accurate and timely data on the state of the power system, thus, increasing the possibilities to manage the system at a more efficient and responsive level and apply wide area control and protection schemes. This paper presents results of a survey on communications and technical requirements for applications based on Phasor Measurement Units (PMU). The survey was carried out in the Nordic Region with participants from Transmission System Operators (TSOs) and researchers. The survey focused on documenting the stage of research and development among TSOs and researchers in the Nordic Region, as well as, their plans and visions for the future. This includes planned PMU deployments and prioritization of PMU based applications. Furthermore, a significant part of the survey was an elicitation of communication requirements for applications based on PMU data. In the paper, an examination of the time requirements for these applications in terms of delays and samples per second and comparison similar published specifications is provided.**

***Index Terms*— Phasor Measurment Unit. Wide Area Monitoring and Control (WAMC), WAMC applications communication requirements.**

I. Introduction

ELECTRICAL power networks are a critical infrastructure in modern society. Our dependence and demand on electricity has risen sharply while recently this rising demand for electricity has been met with a serious strain in terms of production and expansion of transmission capacity. This is due to increasing environmental policies and costs among other factors.

There is an international interest and implementation drive, in both academia and industry, on the prospects of Phasor based monitoring and control technology [1][2]. These systems promise to offer more accurate and timely data on the state of the power system increasing the possibilities to manage the system at a more efficient and responsive level and apply wide area control and protection schemes [3].

Such systems are needed in the modern electrical power system, where transmission expansion is limited by monetary and environmental regulations. Furthermore, the re-regulation of the electrical market and the connection of national grids with neighbouring nations have resulted in a more complex and dynamic environment, in which multiple organizations coordinate and cooperate in the operation and control of the power network.

There have been various research and industrial initiatives by universities and Transmission System Operators (TSOs) in the Nordic region for the implementation and study of PMUs. The Nordic Region in this case constitutes Sweden, Norway, Finland, Iceland and Denmark. These countries have a common connected transmission grid known as NORDEL (Iceland is in the NORDEL organization but its grid is not physically connected to any of the other members) [4]. This report summarizes a survey carried out in the Nordic region (with the exception of Iceland) to study the current practices and future plans of researchers and TSOs for the implementation of PMU based Monitoring and Control Systems.

A. Purpose

The purpose of this survey is to examine and document the stage of research and development among TSOs and researchers in the Nordic Region. Specifically, this is done by examining the current state of PMU deployments and application development and specific communication and data requirements on five commonly concerned PMU-based applications requirements. The five application functions are: Oscillation detection, Voltage stability assessment of transmission corridors, Voltage stability assessment of meshed networks, Frequency instability assessment, and Line temperature monitoring [8]. Finally the requirements collected from these applications would be compared with existing documented requirements from the North American Synchrophasor Initiative (NASPI) [5].

B. Outline

The paper begins with a summarization of WAMC architectures as well as general communication network requirements in section II. These requirements are the basis to building such systems. Section III goes on to discuss the current PMU deployments and application in the Nordic

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region. Furthermore, the requirements for PMU based application as seen by TSO and researchers are presented in Section IV, followed by a general comparison with NASPI requirements are outlined in section V. The paper is concluded in section VI. Finally an appendix containing tables summarizing the requirements for the PMU application functions mentioned earlier is provided in Section VIII at the end of the paper.

II. General WAMC Communication Requirements

Generally, most of the effort internationally [1][2][5][14] has been on developing monitoring and assessment application based on PMU measurements, in addition to platforms that would support these applications, e.g. the Gridstat project [15]. Monitoring and assessment applications are known as Wide Area Monitoring Systems (WAMS), these new application were previously not possible with SCADA measurements due to its generally low data sampling rate and quality, as well as time synchronization. There has been generally less work on developing control systems for PMU based monitoring and assessment application.

A complete PMU based Monitoring and Control Systems is a system by which PMU measurements are collected from various locations on the electrical grid in a nation or region. The measurements are then used by an assessment or monitoring application which would raise alarms or calculate results. The alarms raised and results calculated by these monitoring systems are in turn used to provide corrective actions or control on the power grid. Such a complete PMU based system is known as a Wide Area Monitoring and Control System (WAMC).

A. WAMC Components

WAMC system includes four basic components: A PMU, a Phasor Data Concentrator (PDC), the PMU application system and finally the communication network [16].

Logically, there are three layers in a WAMC which in essence is very similar to more traditional SCADA systems. Figure 1 illustrates the logical architecture of WAMC systems. Layer 1 where the WAMC system interfaces with the power system on substation bars and power lines is called the Data Acquisition layer this is where the PMUs are placed. Layer 2 is known as the Data Management layer and that is where the PMU measurements are collected and sorted into a single time synchronized dataset. Finally Layer 3 is the Application Layer that represents the real time PMU based application functions that process the time synchronized PMU measurements provided by the Layer 2.

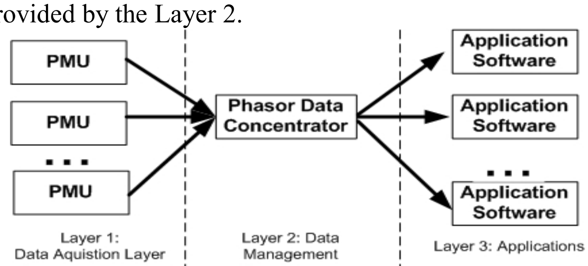

Figure 1: Layers and components of WAMC system.

B. Communication Network

The communication infrastructure is an important component in the architecture of WAMC. This is because PMU devices would be distributed on a wide area, covering various locations within a nation's boundaries. The PMU devices are then connected to a central control center or several control centers over the communication network. Therefore the communication network is a possible bottleneck in the architecture of these systems, since, the delays and data quality of the remote data from PMUs would depend on the communication infrastructure' capabilities and architecture.

Several research and experiences have suggested the use of fiber optic as the main communication media for PMU communication networks [14][18]. This generally resembles the architecture depicted in Figure 2. The network architecture would be composed of a main optical fiber backbone connected to the substation router. In turn the PMU can be connected to the substation router. The PMUs would be connected with the substation router through the standard substation Local Area Network (LAN). The measured phase angles from the PMUs are then transferred to a PDC which sorts and synchronizes the phasors according to the time stamps. The PDC also performs error checking and other functionalities such as data archiving.

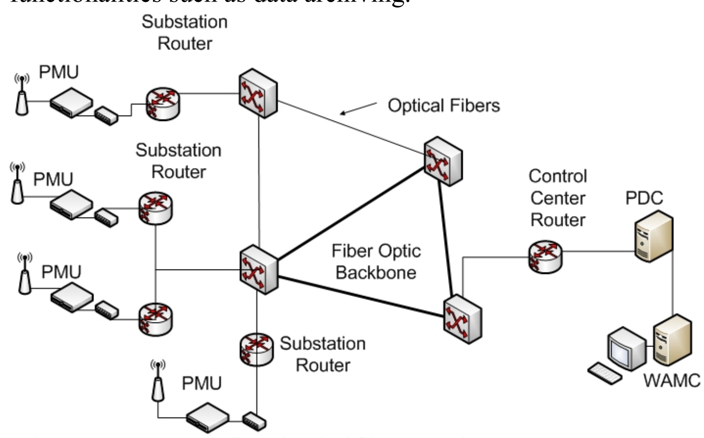

Figure 2: PMUs on a dedicated optical fiber network.

The main argument for using point to point optical fibers is for minimizing the effects of delay. Delay is an important measure to the success of PMU based application. Power system phenomenon could then be observed directly in real time rather than from post disturbance analysis.

On the other hand, a wide area shared network based on TCP/IP protocol suite, rather than a dedicated optical fiber network can be used. In such a network, illustrated in Figure 3, the traffic from PMU devices would be accompanied by traffic from substations RTUs as well as other network uses such as utility Voice-over-IP.

The media of network infrastructure in this case may, be optical fibers, but may also include other communication technologies used by modern utilities such as microwave and radio. The main concern that arises in this case is the reliability of these media as well as to the reliability of the TCP/IP protocol suite as the main communication protocol for critical power system communication. The diverse media may introduce a higher degree of delay due to their inherent physical properties

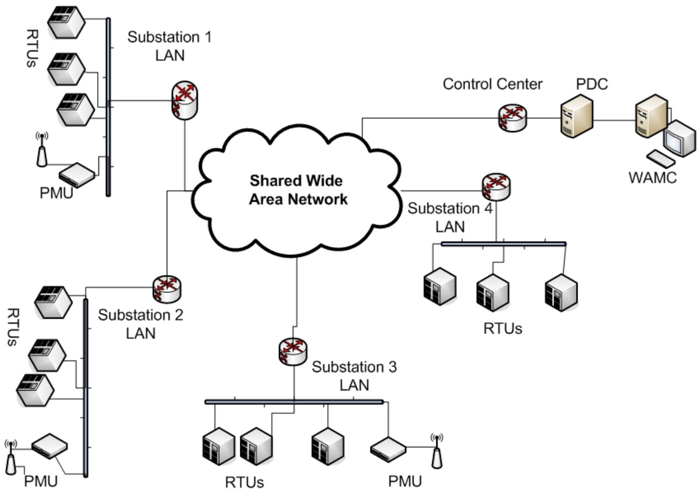

Figure 3: PMUs on a shared Wide Area Network

Real time wide area monitoring and control systems require stringent time requirements in order indentify, analyze and respond to emergency phenomenon in the power system, according to [14] and [16]. Table 1 presents estimations on the total time delay assuming that the system responds automatically to the emergency phenomenon (i.e. in the case of wide area protection scheme):

Activity	Time
Sensor Processing Time	**5 ms**
Transmission Time of Information	**10 ms**
Processing Incoming message queue	**10 ms**
Computing time for decision	**100 ms**
Transmission of control signal	**10 ms**
Operating time of local device	**50 ms**
Total Time	**185 ms**

Table 1 : Time estimates for steps in wide area protection [14]

This estimation depends on the assumption that the optical fibers are used as the main medium of the network and that the nodes and applications are optimized [14].

III. Current PMU Deployment and Applications

The survey was made up of thirteen semi-structured questions that were sent out to TSOs and researchers involved or are planning to be involved in PMU project implementations. The survey was sent out in the form of emails, as well as face to face interviews conducted on the TSOs/researchers' premises.

Part of the survey was aimed at collecting information on current activities, deployments and applications being executed or developed by researchers and TSOs in the Nordic region. In this section these results are presented. Specifically, information on current and planned PMU deployments by TSOs is presented as well as offline and online applications being developed and used. Finally a discussion on communication and information insights is summarized.

A. Current and Planned Deployments

In general the participants in the Nordic survey are still in the early phases of WAMC application functions development and deployment with the main focus being mostly on deploying PMUs and developing WAMS applications. Statnett (Norway) and Fingrid (Finland) are in the most advanced stage in WAMS applications, in comparison to other TSOs, with the development of prototype Oscillation monitoring system. Norway will begin testing control applications using Static Var Compensators (SVC) in cooperation with ABB. Both Statnett and Fingrid have deployed PMUs in substations and have a functioning PDC, a prototype online application function and exchanging PMU measurements. Figure 4 illustrates the current number of PMU and PDC installations in the Nordic region.

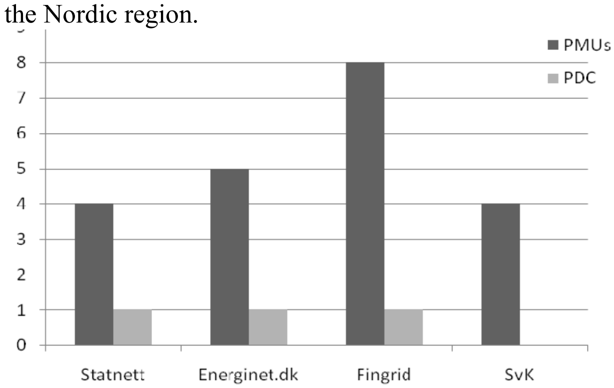

Figure 4: Current PMU and PDC deployments in the Nordic Region

Statnett has four installed and operational PMU connected to one PDC. There is one PMU in the east Norway on the on the main interconnections to Sweden, another PMU is located in the south near HVDC connection to Denmark. The other two PMUs are located in the northern and western part of the Norwegian power system. The PMUs installed in Norway use the IEEE 1344 protocol [19]. Statnett is also upgrading Digital Fault Recorders (DFR) to PMUs.

Fingrid has eight PMUs installed and operational, of which three are in the north and five in the south of Finland. All PMUs in Fingrid are connected to one PDC. Furthermore, Statnett and Fingrid exchange PMU measurement from their respective PMU over the Electronic Exchange Highway, which is a communication link for Nordic utilities with a capacity of 2 MBits/s.

Svenska Kraftnät (SvK), Sweden, has made four PMU installations. These PMUs are currently not online or operational. SvK has taken a policy of PMU installation as they refurbish their substations. Engerginet.dk (Denmark) has five installed and operational PMUs, four in Denmark and one in Germany, all PMUs stream using IEEE C37.118 [20] over TCP/IP.The following Figure 5 illustrates future plans in terms of PMU and PDC installations for Statnett, Fingrid, SvK and Energinet.dk

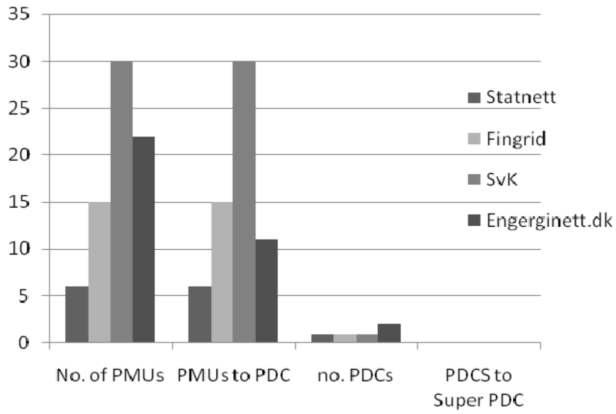

Figure 5: planned PMU installations and PMU to PDC connections

In addition, there are research deployments in Sweden and Finland being studied by the several universities. Four PMUs are deployed in Sweden at universities and one in Tampere, Finland.

B. Current Applications

Generally most of the application developed or purchased by TSOs in the Nordic regions has been for offline studies and analysis of phase angles from PMUs. But they are some online monitoring and analysis software being developed.

Statnett's offline applications are generally for surveying historical data in respect to trends in voltages, frequency and power oscillations. PMU measurements are also used for fault analysis if the disturbance occurred in the vicinity of an installed PMU. In addition, the tools for analyzing PMU measurements are also used to analyze data from fault recorders. Statnett as well use the MATLAB based "Morten Tool" [2] for offline or post disturbance analysis. Likewise Fingrid also has tools for analysis and studies, specifically, disturbance analysis and grid model verification and use mostly ABB's PSGuard for this. Energinet.dk has basic software for collecting and archiving PMU measurements for future studies.

As mentioned earlier SvK has deployed PMUs but they are not operational, so they do not yet have any offline (or online applications), but they have initiated some projects, notably phasor measurement integration into state estimation, and specifically in accuracy improvement for estimates. Two implementations combining PMU signals with SCADA measurements were tested in a MATLAB based power grid model. And also one optimum PMU placement with the objective to enhance estimation accuracy is studied as well.

In terms of online applications Statnett is developing LABVIEW based analysis and visualization software. In which they can view all variables measured by the PMUs and observing active and reactive power flows on incoming and outgoing lines. In addition, both Statnett and Fingrid are developing Oscillation Monitoring applications in cooperation with ABB. Energinet.dk also been developing a MATLAB based application for online visualization of measurements from PMUs.

C. Information Exchange Architecture

Since the stage of WAMC systems is still in development in the Nordic region, the communication architecture has been given basic considerations. Most TSOs in the region are satisfied with their current set up. Nearly all TSOs are using shared network, except Sweden that would have dedicated channels for their PMUs when they become operational.

In General All TSOs will adapt C37.118 as the main protocol for PMU data, Statnett still uses IEEE 1344 but has installed some protocol translators and will upgrade to C37.118. The TSOs seemed to that currently shared using TCP/IP is sufficient for development.

Fingrid and Statnett exchange PMU measurements through the Nordic Electronic Highway (EH) information exchange network. Fingrid has reported some delays on the EH, but that is sufficient for now. In that architecture the measurements coming from the PDC in Norway are treated as an ordinary PMU in Fingrid's PDC, and vice versa. Figure 6 illustrates this architecture.

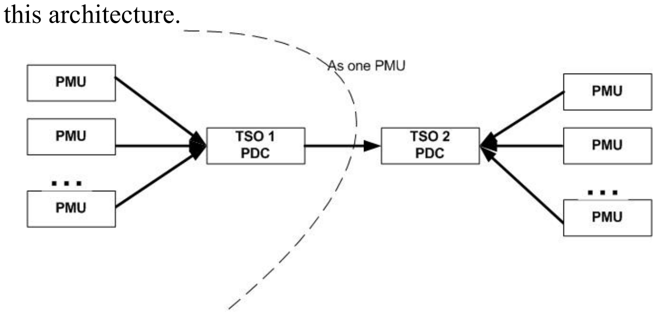

Figure 6: TSO 1 PDC acts as a PMU to PDC at TSO 2

While there are some packet loss and delays on the EH between Statnett and Fingrid, according to Fingrid, most TSOs have commented that this will be the architecture they will choose and that they would not want one single central Super PDC. This results in a meshed architecture of PDC in which from any given TSO the other PDCs are treated as standard PMU measurements. Figure 7 illustrates how a meshed architecture would like. So far due to the development stages in all participants the exact PMU architecture and components that would result and the integration with current SCADA systems are still unclear.

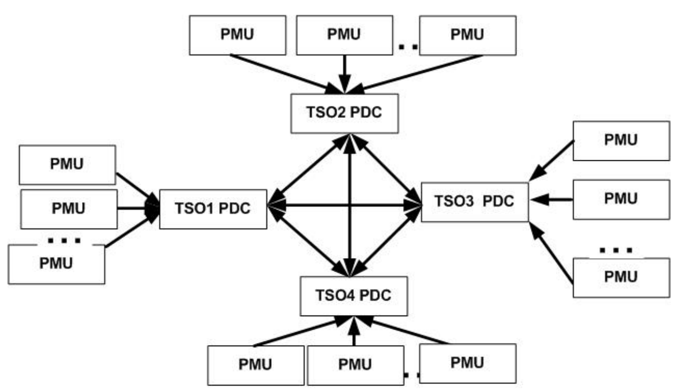

Figure 7: Nordic Phasor Measurements Exchange Architecture

IV. WAMC Applications Requirements in NORDEL

This section discusses communication requirements for the PMU-based applications. The participants were presented with the same 13 questions for each application function. The purpose of the questions was to collect requirements on such issues as time to complete assessment, time window for response to phenomenon, PMU sample rate requirements and protocols as well as possible control functions that could be based on these applications. The answers were then compared with NASPI's application classification and requirements [22].

The appendix at the end of this paper contains the requirements summarized in the tables for each application function. The column headings are requirements that were collected for each application. Latency expected requirement is the amount of time it takes for the phasors to be sent from the PMU until they arrive at the application processing this information. Data resolution is the number of phasor samples required by the application.

Expected time window for response is the amount of time that the application needs for processing the incoming data and outputting the result either raising an alarm or initiating a corrective control scheme in the case of anomalies in the power system. Data source indicated whether other sources of input other than phase angles are needed for the application function, e.g. measurements from SCADA.

The participants also were asked about the format of the data i.e. which protocol would be used for the transmission of information from the PMU to the WAMC. The next column indicates the time required for the execution of currently implemented control schemes that used to remedy anomalies, e.g. current voltage instability control schemes. Finally, the last column indicates the time required for the execution of control schemes that would be based on the results of the PMUs based application.

In the discussion and in the tables the respondents have been made anonymous for sensitivity reasons. The TSO are referred to as TSO 1, 2, 3 and 4. while the researchers from research institutes are referred to as Research Institute 1, 2 and 3.

A. Application prioritization in NORDEL

Five PMU based application functions [8] were presented to TSOs and researchers in the Nordic region and they were asked to prioritize the importance of each application function in their opinion and in terms of their needs. The participants were then asked specific communication delays and response requirements for each application in addition to information on the required resolution and possible feedback control schemes.

Figure 8 presents the priorities of TSOs in the Nordic region. The figure illustrates the similarities in priorities. There is only a slight variation between the priorities and this can be due to the configuration of the power grid and to the presence of different generation portfolio. E.g. Denmark has a larger percentage of wind power generation than any other nation, which could explain why voltage stability applications is critical to them.

Statnett and Fingrid have identical priorities in terms of application functions, while SvK shares some similarities especially in terms of prioritization of Oscillation detection. Note, that most TSOs viewed voltage stability of transmission corridors and that of meshed networks as the same functionality and provided the same requirements (as discussed the later sections) in terms of response time and resolutions, but prioritized each application function differently, in tems of implementation, except Energinet.dk that prioritized them the same.

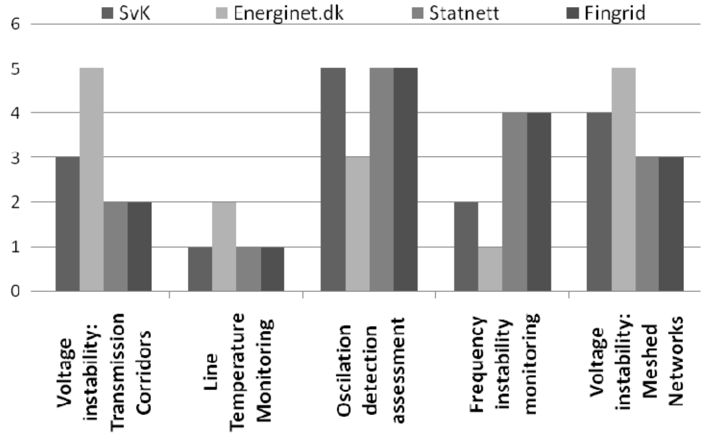

Figure 8: Applications Prioritizations in the Nordic Region

B. Oscillation monitoring and control

With the exception of TSO 3 which considers oscillation monitoring of medium importance among the applications included in the survey, all other TSOs in the Nordic countries listed oscillation monitoring with their highest priority.

Usually power systems are mostly influenced by the low frequency oscillation in the range of 0.05 Hz to 2 Hz [15] and the required latency for this application is considered to be dependent on the targeted oscillation frequency. TSO 1 aims at a refresh rate less than 2 second which is higher than that of their current SCADA/EMS. For TSO 3 the normal communication time, from 0.25 seconds to 2 or 3 seconds, is sufficient. The latency suggested by Researcher 1 and 3 together with TSO 2 is in seconds and by Researcher 2 is in fractions of seconds. Generally, suggested data resolution is in the range from 10 to 50 Hz for all the interviewees. Specifically, for online applications, TSO 4 believes 10 Hz is sufficient, and for offline applications, the sample rate should reach up to 50 Hz. The proposed time window is in fractions of seconds for TSO 1 and TSO 2. Research Institute 1 indicates that time window for the automatic control is more critical comparing to the control schemes executed manually. And Research Institute 2 believes this number should be below the 1/10 of the captured oscillation cycle and a fast response contributes a higher reliability and efficiency. All the participants believed that current SCADA is not sufficient for this application. And as for other applications, they preferred communication protocol is C37. 118.

TSO 1 has initialized a R&D project introducing "global" measurements from PMU to the PSS on SVC aiming to damp the critical oscillation modes. To improve the system damping, Research Institute 1 and 2 have scheduled tests of utilizing wide area measurements in the control of HVDC and FACTs components. Most of the TSOs have the ambition to have the control schemes executed in fractions of seconds. Table 2 in the appendix summarizes the participants' requirements on this application function.

C. Voltage instability assessment

In the survey the users were queried for requirements on voltage instability assessment of transmission corridors and meshed networks as two separate application functions, but most respondents considered these two applications as being the same. However, some TSOs who have significant large percentage of meshed network choose different priorities for these applications, giving a higher priority for assessment of voltage instability in meshed networks. TSO 3 prioritized these two items equally, as the highest, since their grid network does not contain significant transmission corridors compared to the other three countries whose network spans larger geographical distance. Besides it, the large percentage of wind power in that nation's generation portfolio also contributes the voltage instability as TSO 3's critical concern.

In general the latency requirement depends on the time frame for voltage instability phenomenon. In Nordic countries, the long term voltage stability issue is more critical. According to TSO 4 and Research Institute 1, the accepted time delay is in the order of a few seconds. And to TSO 3 and Research Institute 3, time delay is of comparably low importance for this application, and their expected delay is 0.5 minutes and 1 minute respectively. Researchers TSO 3 and Research Institute 2 consider a low resolution to be sufficient for this application while Research Institute 3 suggested a high resolution as 50 samples per second. When it comes to the question of expected time window related to the application response, the Swedish researchers give answers in the range from seconds up to 1 minute.

Most researchers expected the data for the voltage stability assessment application function to come from a hybrid measurement set combined from SCADA and PMU information while the others claimed a fast and reliable SCADA is also accepted. The recommended communication protocol for PMU measurements is C37. 118.

TSO 4 has been using a state estimation based voltage collapse detection program, to assess voltage stability among several transmission bottlenecks for years [23]. Based on the obtained results, control schemes, like control of HVDC links for emergency power regulation, can be executed to maintain the voltage stability. And from their experience, the entire operation takes 2 or 3 seconds and current delay is from 0.2 to 1 second when the dedicated communication channels with redundancy are used. The requirements for this application function are summarized in table 3 in the appendix.

D. Frequency instability monitoring

TSO 1 and TSO 2 have prioritized frequency instability assessment as second important, while TSO 3 and TSO 4 consider it of relatively low importance comparing to other applications involved in the survey.

TSO 2 and Research Institute 3 expect the latency of this application in order of few seconds and TSO 4 considers it to be in fractions of seconds. Research Institute 3 claimed the delay for this control function is mainly decided by the reaction time of the operators. The expectations for the data resolution lie in the range from 1 Hz up to 50 Hz. To most researchers, a response time window in seconds is sufficient. However, TSO 4 has a higher expectation as 0.15 seconds while Research Institute 2 considers that for this application time window for response is not important.

Currently, no synchronized phasor measurements have been involved in the frequency information based control function. The disturbance in Swedish power grid at September, 23, 2003 has proved that the current SCADA/EMS based under-frequency load shedding is too slow. And also similar experiences can be drawn from TSO 2 [23].

In the future, the remotely collected frequency information is proposed to be involved in generation and load control, power exchange monitoring, power system protections and control of HVDC links. Most researchers preferred the data for frequency monitoring to come from a PMU measurement set in future while there is another that school believes that both SCADA and PMU measurements are acceptable. The recommended communication protocol is also C37. 118 for PMU data exchange.

Several measurements are needed in determination of power system frequency and the data processing takes about 0.05 seconds. TSO 4 has the ambition that the control function based on wide area frequency information should be executed and confirmed in 0.1 seconds while Research Institute 1 and TSO 2 are expecting this function to be completed in a few seconds. The requirements for frequency instability monitoring are listed in table 3.

E. Line Temperature Monitoring

The line temperature monitoring application function is somewhat of a low priority function for TSOs in the Nordic region regarding the applications in the survey, and therefore the response on this application function was rather limited. All TSOs and researchers generally agree that this application function covers a slow developing phenomenon, especially in comparison to the other application functions discussed in this report. The monitoring, detection and the response to such a phenomenon, in terms of time and delay, are not critical.

Some TSOs, for example TSO 1 have commented that this application function is not applicable since their overhead lines go through very different landscapes. On the other hand, TSO 4 has commented that this maybe an interesting project in the future, especially in relation to wind power utilization. Specifically when maximum wind power is being produced at the same time as hydro production, this would result in heavy load on the transmission lines, especially when considering that the transmission lines in that nation were built to match the maximum capacity of their hydro production. Table 4 summarizes the requirements for the line temperature monitoring application function according to the participants.

V. Analysis

In general, the requirements collected from the TSOs and researchers dealing with PMU-based application are similar to specifications outline by NASPI. But there are some differences, for example, in terms of voltage instability monitoring, TSOs in Nordic countries generally have a higher ambition considering the response time window comparing to the NASPI classifications. The expectations for frequency instability monitoring from TSOs in NORDEL are fairly similar to NASPI classifications. While their requirement on response time window is again longer, comparing to the NASPI classifications.

In terms of line temperature monitoring the TSO and researchers in the Nordic region have a tighter requirement on response time of the application with is in the order of seconds while in comparison to NASPI's recommendation the response time is approximately 1 hour. Another difference is in the required phasor data resolution where in the Nordic region it is believed that a low data rate (without specifying exactly) is sufficient while NASPI suggestion 30 samples per second.

VI. Conclusion

The aim of this survey is document current stage of WAMC development and deployment in the NORDIC region and to collect application expectations and requirements from TSOs and researchers involved in the development and deployment and compare these results with requirements specified by previous experiences specifically with NASPI. By doing this information could be dissipated in the region and encourage cooperation.

The survey has shown that the aim and goals of participants is more or less similar. While Statnett and Fingrid have made significant progress, especially in application development, the other TSOs and researcher are also deploying PMUs and planning to employ these systems.

In terms of applications functions the prioritization of is more or less identical with minor exceptions. The similarity is also true for the communication requirements and data requirements. Finally, it was found that the development and requirements are also in line with previous experiences, specifically those from NASPI.

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VIII. APPENDIX

Interviewees	Expected Latency	Expected Resolution	Expected Time Window for Response	Format/ Protocol	Time Delay for Current/Tested Control Schema	Expected Execution Time for Control Schema
TSO 1		10 Hz	Less than 0.3 seconds	IEEE 1344 /updating to C37.118	To be determined	
TSO 2	Less than 2 seconds	10 Hz	Fractions of seconds	C37.118	Not applicable	Fractions of seconds
TSO 3						
TSO 4	0.25-2 or 3 seconds	10/50 Hz for online/offline applications		C37.118	0.25 seconds	0.25 seconds
Research Institute 1	Seconds		Seconds/Minutes for automatic/manual control			Seconds
Research Institute 2	Fractions of seconds	Above 10 Hz	Less than 1/10 of the cycle time of studied oscillation	C37.118		
Research Institute 3	1 second	50 Hz	Less than 0.2/5 seconds for POD/SPS		Less than 1 second	
NASPI	1-5 seconds	10 Hz	Seconds	PDC Stream/ C37.118		

Table 2: Oscillation Detection

Interviewees	Expected Latency	Expected Resolution	Expected Time Window for Response	Format/ Protocol	Time Delay for Current/Tested Control Schema	Expected Execution Time for Control Schema
TSO 1						
TSO 2						
TSO 3		Depends on a PhD project output		C37.118		
TSO 4	1 to 2 seconds (Long term)	Low	Less than 1 minute	C37.118	From 200-300 ms to 1 second. (on a dedicated channel)	
Research Institute 1	Above seconds		Up to 1 minute			Several seconds
Research Institute 2	Up to 10 seconds (Long term)	1 to 10 Hz	Fractions of a second or longer	C37.118	A few seconds	
Research Institute 3	30 seconds	50 Hz	2-3 seconds			0-5 minutes
NASPI	Few seconds	30 Hz	Minutes/Seconds for long/Short term voltage stability	C37.118		

Table 3: Voltage instability

Interviewees	Expected Latency	Expected Resolution	Expected Time Window for Response	Format/ Protocol	Time Delay for Current/Tested Control Schema	Expected Execution Time for Control Schema
TSO 1		5-10 Hz				
TSO 2	Seconds		Seconds	C37.118	Not Applicable	Less than 5 seconds
TSO 3						
TSO 4	0.25-0.5 seconds	50 Hz	0.15 seconds	C37.118	Not Applicable	0.1 Seconds
Research Institute 1			Seconds		Under frequency load shedding was too slow on September 23 2003.	Seconds
Research Institute 2	1/10 of the operator reaction time	1-10 Hz	Not important		Fractions of a second.	
Research institute 3	1 second	10 Hz				1-2 seconds
NASPI	1-5 seconds	30 Hz	Few minutes	PDC Stream/ C37.118		

Table 4: Frequency Instability

Interviewees	Expected Latency	Expected Resolution	Expected Time Window for Response	Format/ Protocol	Time Delay for Current/Tested Control Schema	Expected Execution Time for Control Schema
TSO 1						
TSO 2	Minutes		Minutes			Minutes
TSO 3	Slow phenomen on, slow process	1 Hz	Less than 1 second	C37.118		
TSO 4	10 minutes	Low Data Resolution				
Research Institute 1	Seconds or minutes		Seconds to minutes			Minutes
Research Institute 2	Few minutes		Fractions of seconds	C37.118		
Research Institute 3	5 minutes	1 Hz				15 minutes
NASPI	Few seconds	30 Hz	1 hour	IEEE 1344 / C37.118		

Table 5: Line Temperature Monitoring