NATIONAL ELECTRIC POWER COMPANY
TENDER NO. 31/2023 for Supply of
Phasor Measurement Units/Wide Area Monitoring System
PMUs/WAMS

1. Acronyms & Abbreviations

Abbreviation	Description
IEC	International Electro technical Commission
IEEE	Institute of Electrical and Electronics Engineers
GPS	Global Positioning System
CT	Current Transformer
VT	Voltage Transformer
PMU	Phasor Measurement Unit
PDC	Phasor Data Concentrator
ROCOF	Rate of Change of Frequency
UTC	Universal Time Coordination
IRIG-B	Inter-range instrumentation group time codes group B
iSCSI	Small Computer System Interface protocol over TCP/IP
SFP	Small Form-factor Pluggable
IGMP	Internet Group Message Protocol
GVRP	Generic VLAN Registration Protocol

RAID	Redundant Array of Independent Disk
HQ	Head Quarter
ACL	Access Control List
NCC	National Control Centre (at Amman South)
NEPCO	National Electric Power Company
NTP	Network Time Protocol
NTU	Network Termination Unit
OEM	Original Equipment Manufacturer
OS	Operating System
OOB	Out Of Band
QoS	Quality of Service
SNMP	Simple Network Management Protocol
SSH	Secure Shell
SAN	Storage Area Network
VLAN	Virtual Local Area Network

PDF	Portable document Format
XLS	Microsoft Excel spreadsheet file
CSV	Comma Separated Value
XML	Extensible Markup Language
SAS	Serial Attached SCSI
DDR4	Double Data Rate Fourth-Generation
LACP	Link Aggregation Control Protocol
LOA	Letter of award
MTBF	Mean Time Before Failure
MTTR	Mean Time To Recovery, Repair, Respond, or Resolve
NCC	National Control Center
CPT	Custom post type
WAMS-per	Wide Area Monitoring System peripherals
WAMS	Wide Area Monitoring System

2. General for National Electric Power Company (NEPCO)

NEPCO is the state-owned single buyer of all electricity produced in Jordan, but it also has several other roles, including System Operator, owner of the transmission network, and fuel purchaser. Through its multiple functions, NEPCO has a deep understanding to develop broad electricity sector strategies to ensure that in the future, power continues to be supplied without interruptions and at optimal prices.

As the System Operator, NEPCO ensures safe and optimized dispatch of individual power units. NEPCO is responsible for connecting the new generation capacity with the transmission network and ensuring that the appropriate grid expansion and upgrade investments are undertaken to maintain the power grid (in terms of voltage and frequency). The risk of power blackouts is sufficiently mitigated. NEPCO would also determine the dispatch of the generation plants, including requiring certain power plants not to produce for a certain period.

NEPCO owns, maintains, and develops the transmission system in Jordan and operates the power interconnection with Egypt and Syria as the transmission network owner.

NEPCO ensures that the interconnections with neighboring countries are sufficient to deliver the required reserve capacity, particularly if the amount of reserve available within Jordan is insufficient.

Jordan's electric power grid has been gradually modernized since the mid-1980s with smart grid technologies in the transmission network and control center. To improve Jordan's power system's management, efficiency, and reliability as it shifts to greater use of variable wind and solar generation, the national electricity power company (NEPCO), the transmission system operator and dispatch controller, wish to modernize its grid monitoring and control systems further.

The significant changes in Jordan’s energy mix over the last six years, rapid changes in technology, and changes in technology costs are driving Jordan to reconsider how to incorporate “smart grid” approaches into its power system.

According to the above facts, NEPCO wants to study the grid's stability in the best practice and effective way an invitation for the PMU tender with WAMS is currently available. Currently, the PMUs will be installed into 17 substations and shall be capable to integrate to the SCADA/EMS system while the WAMS will be installed inside NEPCO NCC, and this system shall be capable of the planned future expansion of the system.

3. Scope of Work

The scope of work shall include design, supply, configuration, integration, commissioning, and training on the offered system, like the following:

a) Full design for PMUs/WAM system based on site installation due to the selected circuits.
b) Delivery of the full system equipped for all PMU/WAMS system to CPT basis.
c) Configuration, and integration the PMUs and PDC (if used) in the substations, conforming to the latest applicable standards of IEC/IEEE 60255-118-1, IEEE C37.118 and implementation of the backup solution and policies to back up the overall system to this storage device.
d) Configuration of main ICS firewalls and Ethernet switches in NCC, taking into account implementing out-of-band management for devices and appliances in NCC.
e) Installation and configuration of the latest versions of OS and WAMS software, high availability approach and confirming the recommended security best practices to harden and secure the servers and operating system.
f) Commissioning for WAMS and central PCD systems (software applications and peripherals)
g) Training of the Employer personnel for at least two weeks (10 working days) to allow NEPCOs team to operate and maintain the system effectively.
h) Maintenance and technical support regarding any raised issue to enable NEPCO staff to connect and integrate the system for two years. Support does not include network devices, firewalls, and workstations.
i) Supply of spare parts.
j) Factory Acceptance Test (FAT)
k) The provision of a GPS units and its corresponding accessories for PMUs in each substation.

4. Out of Scope

NEPCO's responsibilities will include the following based on the supplied design from the contractor:

a) Installation the PMUs and connection with the CTs and VTs
b) Supply and install all cabling, wiring, terminations, and interconnections to the equipment, including necessary trench/surface conditioning to interconnect the PMUs, PDCs, WAMS, and data network cabling.
c) Install and configure network devices in substation
d) Installation of GPS and its Antenna in substations and NCC
e) Install NCC's servers, shared storage, KVM switch, and workstations, and successfully connect these devices to the existing infrastructure.

5. Proposed Timetable

	Description	Duration
1	LOA	0 month
2	Final design stage and submit of all technical documents	10 months
	FAT test for integrated system	
	Deliver the equipment from LOA	
3	Delivery and receipt	One month
4	Commissioning of system and site construction	Three months
5	Onsite Implementation	One month
6	Acceptance and energized the system	One month
7	Training for WAMS application, WAMS-per and the PMUs	As table in section 12

6. General for Technical of PMUs/ WAMS system

WAMS consists of four major building blocks: Phasor measurement units (PMUs), Phasor Data Concentrators (PDCs), WAMS master, and the data systems infrastructure and applications. Real-time synchro phasor data collected by the PMUs are aggregated using PDCs and then reported to the WAMS master located at the national control center (NCC). The data system infrastructure and applications provide the medium for data transfer, processing, storage, handling and visualization.

7. The required standards

Operational standards:

- IEEE C37.118.1 2011 IEEE Standard for Synchrophasor Measurements for Power Systems.
- IEEE C37.118.1a 2014 IEEE Standard for Synchrophasor Measurements for Power Systems -- Amendment 1: Modification of Selected Performance Requirements.
- IEEE C37.118.2 2011 IEEE Standard for Synchrophasor Data Transfer for Power Systems.

- IEEE C37.244-2013 - IEEE Guide for Phasor Data Concentrator Requirements for Power System Protection, Control, and Monitoring.
- IEEE C37.111:2013 - Measuring Relays and Protection Equipment - Part 24: Common Format for Transient Data Exchange (COMTRADE) For Power Systems.
- IEEE C37.232-2011 - IEEE Standard for Common Format for Naming Time Sequence Data Files (COMNAME).

Communication standards:

- IEEE C37.118.2-2011 - IEEE Standard for Synchrophasor Data Transfer for Power Systems.
- IEC 60870-5-104 - Network access for IEC 60870-5-101 using standard transport profiles.
- IEC 61850-90-5 - Use of IEC 61850 to transmit synchrophasor information according to IEEE C37.118.
- IEEE 1815-2012 - IEEE Standard for Electric Power Systems Communications-Distributed Network Protocol (DNP3).
- OPC Unified Architecture (OPC UA) protocol

Cyber security standards:

- IEEE C37.240-2014 - IEEE Standard Cybersecurity Requirements for Substation Automation, Protection, and Control Systems.
- IEC 62443 series of standards for Industrial Automation and Control Systems (IACS) security.
- IEC 62351 Standard Series - Data and communications security for power systems management and associated information exchange.
- NERC CIP Standards.
- NEPCO's Cybersecurity Requirements for Industrial Control Systems (ICS).

Manufacturing standards:

- Electromagnetic Compliance Power Supply:
  - IEC 60255-11: 2008 Measuring Relays and Protection Equipment – Part 11.
  - IEC 60255-26: 2013 Measuring Relays and Protection Equipment – Part 26.
- Humidity Compliance:
  - IEC 60068-2-30: 2005
- Vibration Compliance:
  - IEC 60255-21-1: 1988 Vibration Tests
  - IEC 60255-21-2: 1988 Shock and Bump Tests
  - IEC 60255-21-3: 1993 Seismic Tests
- Surge Withstand Capability (SWC):
  - IEC 60255-22-1 - 2007

  - IEEE/ANSI C37.90.1: 2002
- Dielectric Strength Compliance:
  - IEC 60255-5:2000.
  - ANSI/IEEE C37.90-2005
- Impulse Compliance:
  - IEC 60255-5: 2000 - Part 5 Impulse Voltage Tests.
  - ANSI/IEEE C37.90-2005.

The Bidder/Contractor shall provide details on the country of origin for the offered solution.

8. Phasor Measurement Units (PMUs)

8.1 General for Phasor measurement

The Phasor Measurement Unit (PMU) is one of the major building blocks of a Wide Area Monitoring System (WAMS).

PMUs shall be supplied for acquiring real-time synchronized phasor measurements that will enhance NEPCO's monitoring capabilities. They shall be installed at specific locations within NEPCO System.

PMUs shall process voltage and current from standard Protection core (class x or 5P20) Current Transformers (CTs) and Voltage Transformers (VTs) to provide high quality, synchronized phasor voltage and current measurements. The substations typically are provided with CTs on each bay of the switchyard and CVTs in each transmission line bay. Generally, CTs have one metering core and four protection cores. The CVTs are provided with two cores, one for measuring and the other core for protection. The PMUs to be supplied and connected to protection CT and CVT cores.

This specification covers the design, functionalities, manufacturing, factory testing, installation, on-site commissioning of PMUs.

The specification also provides NEPCO's functional and performance requirements for PMUs.

The main features of a PMU shall be:

- Fully compliant with latest applicable standards of IEEE C37.118.1-2011 synchrophasor measurement standard, including the amendments in C37.118.1a-2014;
- Fully compliant with IEEE C37.118.2-2011 synchrophasor data transfer standard;
- Independent PMU functionality;
- Minimum 2 digital inputs and 2 digital outputs for each connected circuit;

- An accurate crystal controlled clock with external GPS synchronization facility for a time tag accuracy of 1□s
- All the measurements shall be tagged with UTC (Coordinated Universal Time). The time tagging accuracy shall be at least one micro-second.
- The PMUs should be capable of adjusting the data sampling rate to 10, 25, or 50 samples per second. The user should have the option to select the desired sampling rate, but the default configuration should be set to 50 samples per second.
- The PMUs must possess a continuous self-monitoring and diagnostic capability. They should be able to detect and communicate any issues or abnormalities, generating alarms as necessary. These alarms should be displayed locally on the PMUs and also transmitted to the Phasor Data Concentrator (PDC).
- Low power consumption powered by the station battery;
- The PMUs will establish communication with the Phasor Data Concentrator (PDC) through an Ethernet interface using the employer-provided communication link. Each PMU should have two redundant communication ports capable of transmitting data as our required standard, with a speed of 10/100 Base Tx for TCP/IP. Additionally, there will be additional optical remote communication ports available, also capable of streaming data in our required standard, with a speed of 10/100 Base Tx for TCP/IP.
- Cyber security features for compliance with international industry standards.

8.2 Technical Description for PMUs

The PMUs required in this specification must supply phasor and analog data regularly. These PMUs should be fully functional and ready for installation at the substation, capable of communicating with the Phasor Data Concentrator (PDC. Here are some of the requirements that need to be fulfilled:

8.2.1 Reference Standards:

All PMU components shall be designed and implemented in reference to the related standards, in section 7.

8.2.2 Network Integration and WAMS Architecture

PMU synchrophasor data is streamed to local and/or central PDCs located at NCC control center. WAMS are equipped with the required software to permit the visualization and analysis of synchrophasor data.

In addition, synchrophasor data shall be stored locally in every substation/substation-pair through the PMUs itself, local PDC or alternative equivalent appliance. The local storage shall be capable to keep all data within the substation for at least five days.

The Bidder/Contractor shall be aware that the offered PMUs must support a seamless integration with the central PDCs and WAMS applications at the NCC control centers.

8.2.3 Hardware Requirements

a. Electrical Requirements

The auxiliary power supply of the PMU will be supplied from the substation redundant DC distribution system. Accordingly, the PMU shall have redundant 110V DC power supply with (+15%, -20%) tolerance.

b. Input Channels

The analog AC voltage and current input channels shall be rated at 110 V (phase-to-phase) and 1A, respectively, with a frequency range of at least 45Hz to 55Hz at f_{rated} = 50Hz.

The analog channel for the voltage input shall be provided with the maximum amplitude of recording to be at least 1.2 times the nominal value, while the analog channel for the current input shall be provided with the maximum amplitude of recording to be at least 2 times the nominal value for steady state, while the PMU shall be capable to carry at least 10 times the nominal value for at least on second in case of faults.

The accuracy of the current and voltage inputs shall be better than 0.5% of the full scale. It shall be possible to modify the scaling factor for each input channel to calibrate the measurements as needed.

The Bidder/Contractor shall determine the suitable calibration for each input channel to ensure all measurements meet the accuracy requirements, especially for circuits running at minimum load. The determined calibration shall be validated with NEPCO at time of detailed engineering and commissioning.

The PMU shall also have a minimum of two digital inputs and two digital outputs for each connected circuit, all freely configurable.

The total PMUs shall be suitable and adequate to connect (180) circuit. The following specifications are necessary for each circuit:

- Four analog voltage channels
- Four analog current channels
- At least two digital input channels

- At least two digital output channels

The distribution of the PMUs across the 17 substations can be found in the table below:

Sub-station name	Connection point	Voltage Level	No. of Circuit
AMMAN SOUTH	1	400 kV	4
REHAB	1	132kV	11
MWAQAR	1	132kV	8
Q. ALIA	2	132 kV	6
		400 kV	4
MANARA	1	132 kV	10
AMMAN EAST	1	400 kV	11
	1	132 KV	11
SAMRA	2	400 kV	10
		132 kV	15
AMMAN NORTH	2	132 kV	8
		400 kV	5
AMMAN WEST	1	400/132kV	8
ZERQA	1	132kV	12
QWIERA	1	132 kV	6
QATRANEH	1	132 kV	13
MAAN NEW	1	132kV	12
ATPS (400) / AIS (132)	2	400kV	6
		132kV	4
TAFILA WIND	1	132kV	6
RISHA	1	132kV	10
TOTAL	17		**180**

*Please note that the distance between the two points (400KV and 132KV) in the Q.ALIA and Amman north substations is greater than 300 meters but less than 1 kilometer.

* Please note that the distance between the two points (400KV and 132KV) in the AIS and ATPS substations is greater than 30 kilometer.

*Please note that the distance between the two points (400KV and 132KV) in Samra substations is greater than 4 kilometer.

c. **Communication Channels**

The PMU must have a minimum of two 1000Base-TX Ethernet communication ports for fast and easy communication with upstream PDCs. The ports shall be capable of redundant communication by providing seamless failover.

The Vendor shall validate that PMU communication ports have sufficient bandwidth capacity to accommodate output data streams, taking into consideration all possible options for the supported message content, communication protocols and reporting rates.

The Bidder/Contractor shall provide detailed bandwidth calculations and measurements during engineering and commissioning.

PMUs may be required to encompass 1Gbps single mode fiber LAN port as clearly explained later in substation pairs section.

d. **GPS Synchronization**

The PMUs in each substation must be equipped with a GPS system to synchronize its clock with a UTC source. The time receiver should compensate for propagation delays and possess an offset that allows for local time correction, ensuring a time accuracy of at least 1 microsecond. In case the UTC signal is lost, the time receiver should detect this loss and notify the PMU, which will subsequently transmit the event to the PDC, generating an alarm. When the signal is lost, the PMU's time facility should switch to an internal time base. This internal time base must have a minimum stability of 1pps. Within five minutes of signal reacquisition, the time synchronization should return to within 1.5 microseconds of UTC. Additionally, the PMU should incorporate proper correction for leap seconds.

e. **Self-Supervision & Alarms**

The PMU shall be capable of continuous self-supervision to detect hardware and software failures. All types of failures shall be detected and alarmed, which should typically include the detection of internal equipment failures, loss of auxiliary (dc) supply, loss of analog channels, communicate problems, etc. It shall be possible to report PMU alarms to be transferred to upstream PDCs.

Furthermore, the PMU is desired to have self-testing capabilities to lower the dependence on routine maintenance testing.

f. **Engineering Interface**

The PMU shall include configurable LEDs for status indication and other functions. In addition, It is preferred that the PMU includes a graphical LCD for the entry of parameters and the visualization of measurements, events and alarms in chronological order, etc. The PMU shall also be provided with two Ethernet ports for connection of a personal computer for engineering access and maintenance including configuration and firmware updates.

g. **Service Conditions**

The PMU shall be capable of operating in ambient temperatures from -10° C to +50° C with a maximum ambient relative humidity of %77.

8.2.4 Functional Requirements

a. General Functional Requirements

The PMU shall be compliant with P (protection) performance classes as defined in IEEE C37.118.1- 2011 standard. Anti-aliasing filters shall be automatically used based on the selected performance class (P) and the reporting rate in order to cope with the measurement characteristics for P classes as specified in IEEE C37.118.1-2011 and the amendments in IEEE C37.118.1a-2014.

b. Measurements Requirements

The PMU must be able to sample and/or calculate the following measurements:

- Three-phase sequence voltages magnitude and angle (polar form) quantities.
- Three-phase sequence currents magnitude and angle (polar form) quantities.
- Voltage positive, negative and zero sequence magnitude and angle;
- Current positive, negative and zero sequence magnitude and angle;
- Frequency, Rate of change of frequency (ROCOF) & Active and reactive power should be derived either at PMUs or PDCs from the measured values.

The PMUs shall be capable of transferring the all the measured & derived quantities to PDC along with timestamp.

c. Measurements Characteristics Requirements

The PMU shall support the measurements characteristics of P class PMUs including maximum reporting latency, accuracy, resolution and response time as per IEEE C37.118.1-2011 and the amendments in IEEE C37.118.1a-2014. Measurement accuracy shall meet the following minimum requirements:

Description	**Requirements**
Maximum Total Vector Error (TVE)	1%
Maximum phase angle measurement error	0.2 deg.
Maximum current and voltage measurement error at full scale	0.5%
Maximum frequency measurement error	0.005 Hz
Maximum time stamping error	1μs

Any other detailed requirement for measurement accuracy will be according per IEEE C37.118.1-2011 and the amendments in IEEE C37.118.1a-2014.

d. Time Synchronization Requirements

All recorded PMU data shall be time tagged with Coordinate Universal Time (UTC) to the nearest 1μs. In case of loss of GPS signal, the PMU shall automatically switch to the internal clock which shall maintain the accuracy as specified. The PMU shall resynchronize automatically when GPS signal is available again. The time source, whether from GPS clock or internal clock, shall be indicated in the output PMU data stream to the PDCs.

e. Data Format and Data Output Requirements

The PMU data output and communication with upstream PDCs shall be compliant with IEEE C37.118.2-2011. The data to report shall be user configurable. It shall be possible to transfer data in floating point format, with the option to represent Phasor data in polar or rectangular format. It shall also be possible to configure station, device, and measurement channel naming and identification.

f. Communication Requirements

The PMU shall support reporting rates of 10, 25 and 50 frames per second for a 50Hz system, and the actual rate shall be user selectable. The PMU shall also allow communication with at least 2 independent clients, simultaneously, with the ability to fully configure each data stream. Redundant connections with automatic failover capability shall be supported for each client. Moreover, TCP and UDP protocols shall be supported for unicast and multicast transmission of PMU data.

The PMUs shall support the following communication protocols:

- IEEE C37.118.2-2011;
- IEC 61850-90-5; and
- IEC 60870-5-104.

The PMU is desired to optionally support the following communication protocols as well:

- Modbus; and
- DNP3.

The PMU shall be capable of communicating with PMUs and Central PDCs of the same or different manufacturers using open standard protocols. Interoperability and seamless integration shall be ensured.

g. Control Logic Requirements

The PMU shall be equipped with programmable logic for control functionalities, as well as user configurable logic blocks and timers. It shall be possible to configure all available digital inputs and outputs to support autonomous WAMS control and protection applications by a free license software

h. Software Requirements

A tool for user-friendly engineering, monitoring and data retrieval shall be available. The tool shall also allow remote configuration and firmware upgrade of the PMU.

The offered solution shall ensure OS/firmware compatibility with all WAMS components including PDCs and WAMS applications servers.

In case of popular operating system, the OS shall **NOT** be outdated software. The available OEM support for operating system software shall endure for at least five years after suppling the material.

i. Security Requirements

The PMU shall have cyber security features that enable the design of a system in compliance with industry standards for secure handling of the device, including user activity logging, authority handling, user management and system event logging over Syslog to enable a system-wide overview of system events. It shall also have per-port enable/disable capability of engineering access and communication protocols.

The PMU shall comply with international cybersecurity industry standards.

j. Hardware Availability

Bidder/Contractor shall state in its offer the PMU hardware availability while in service i.e. MTBF and MTTR values (where MTBF measures the time between failures for devices that need to be repaired, MTTR is simply the time that it takes to repair those failed devices). In other words, MTBF measures the reliability of a device, whereas MTTR measures the efficiency of its repairs. Supporting document from the manufacturer shall be enclosed.

8.3 Testing & Inspection

8.3.1 General for Testing

All PMU components shall be configured and tested at the Manufacturer's facilities. The Bidder/Contractor may be required to carry out any or all of the tests stated in this specification under witness of NEPCO or its representatives.

Testing of the PMU shall be performed in line with this specification and in accordance with the relevant international standards (as a minimum requirement) and other standards as may be approved by NEPCO.

Acceptance by NEPCO's representatives of any PMU equipment shall not relieve the manufacturer from any of its obligations.

NEPCO reserves the right to perform checks during manufacturing process at any time or all the times. It shall be at the discretion of NEPCO to witness tests on 100%, or any percentage quantity of each lot for routine tests, apart from the type tests, wherever called for, and all the PMUs shall be ready and configured before the testing.

Tests of PMU equipment shall comprise factory and testing.

8.3.2 Factory Tests

a. **Type Tests**

Evidence shall be given that the proposed PMU to be supplied under this specification has been subject to all type tests at an internationally recognized testing facility. If deemed necessary, NEPCO will decide whether additional tests shall be performed by the Bidder/Contractor.

An internationally recognized laboratory approved by NEPCO shall certify the type test reports.

The Bidder/Contractor shall submit certified copies of type test certificates covering the proposed PMU equipment.

Type tests certificates/reports shall be considered acceptable if they are in compliance with the relevant standards and the following:

- Type Tests conducted at an internationally recognized laboratory acceptable to NEPCO.
- Type Tests conducted at the manufacturer's laboratory and witnessed by representatives from an internationally recognized laboratory acceptable to NEPCO.

If the presented type test reports are not in accordance with the above requirements, NEPCO may decide to ask for the type tests to be carried out in the manufacturer's premises or other places subject to the approval of NEPCO and at no additional cost. These tests shall be performed in the presence of an internationally recognized laboratory, which should issue the relevant type test certificates upon successful test.

The type tests to be performed shall comply with NEPCO specification requirements and shall include tests such as, but not limited to, the following:

- Compliance to latest IEEE C37.118 standards.
- Electromagnetic Compatibility (EMC) Immunity test.
- Electromagnetic Compatibility (EMC) Emissions test.
- Safety/Insulation test.
- Environmental test.
- Vibration test.

b. **Routine Tests**

Routine Tests shall be performed, comprising, as a minimum, the following tests:

- Visual checks.
- Functional checks.

- Print layout.
- Verification of the communication links.
- Performing a sample of analysis.
- Performance testing
- Sizing and capacity testing.
- Installation and integration procedures test.
- NCC failover testing.
- Data storage archiving testing.
- Configuration test
- Cyber security testing as per international standards such as IEC 62351-100 conformance testing.
- Cyber security testing as corresponding to the proposed cybersecurity aspects
- Checking other features which are inherited by the system.

8.3.3 Site Tests

Site Tests shall be performed, comprising, as a minimum, the following tests:

- Installation checks.
- Performance testing
- Sizing and capacity testing.
- Installation test.
- NCC failover testing.
- Data storage archiving testing.
- Cyber security testing as per international standards such as IEC 62351-100 conformance testing.
- Cyber security testing as corresponding to the proposed cybersecurity aspects

- Secondary injection for all voltages and currents. If the PMUs are connected to the circuit's Current Transformers (CTs) and Voltage Transformers (VTs) during testing, an on load test (if applicable) for the current can be performed using the actual values of the primary currents.
- Performing the analysis on measurements corresponding to injected/actual values.

- Compatibility to integrate with Central PDCs at NEPCO's NCC control centers, and verify reported PMU data against local measurements.
- Ensure PMU measurements are time-stamped correctly and that the clock is synchronized to UTC and locked on GPS time.
- Ensure PMU measurements including magnitude, phase angle, and frequency are within accuracy requirements and comparable to local substation measurements.
- Ensure the correct digital status indications are being reported.

8.4 PMU Documentation

Complete documentation is required to support PMU setup, operation and maintenance. The documentation shall include the following:

1. Procedures for PMU setup and use concerning all features
2. Documentation of procedures regarding routine maintenance, including the use of system diagnostics.
3. Detailed connection diagrams show how the PMUs are installed at the site.
4. A complete copy of PMUs functional design.
5. Details of PMU database.
6. Details of hardware/software and as-built system.
7. Manuals of PMUs and the manual of software.

All documentation shall be delivered in electronic format (e.g. PDF, MS WORD, Hypertext, etc.) on CDs/DVDs/USB drives and hardcopy format. Sufficient online documentation, such as help screens, user guidance messages, context-sensitive help information links, etc., shall be included with the system to minimize the need for users to consult the hardcopy documentation.

9. Phasor Data Concentrator (PDC)

9.1 General for PDC

In addition, synchrophasor data shall be stored locally in every substation/substation-pair through the PMUs itself, local PDC or alternative equivalent appliance. The local storage shall be capable to keep synchrophasor data for five days.

The Central Phasor Data Concentrators (PDCs) is one of the major building blocks of a Wide Area Monitoring System (WAMS).

Central PDCs will be installed at NEPCO's NCC to aggregate synchrophasor measurements collected by the storage in PMUs or PDC in the network. Two central PDCs shall be installed at NCC with the capability for hot-standby redundancy.

PDC data shall be reported online to a WAMS system for analysis and visualization of synchrophasor data.

This specification covers the design, functionalities, manufacture, factory testing, installation, on-site testing and commissioning of PDCs.

9.2 Technical Description

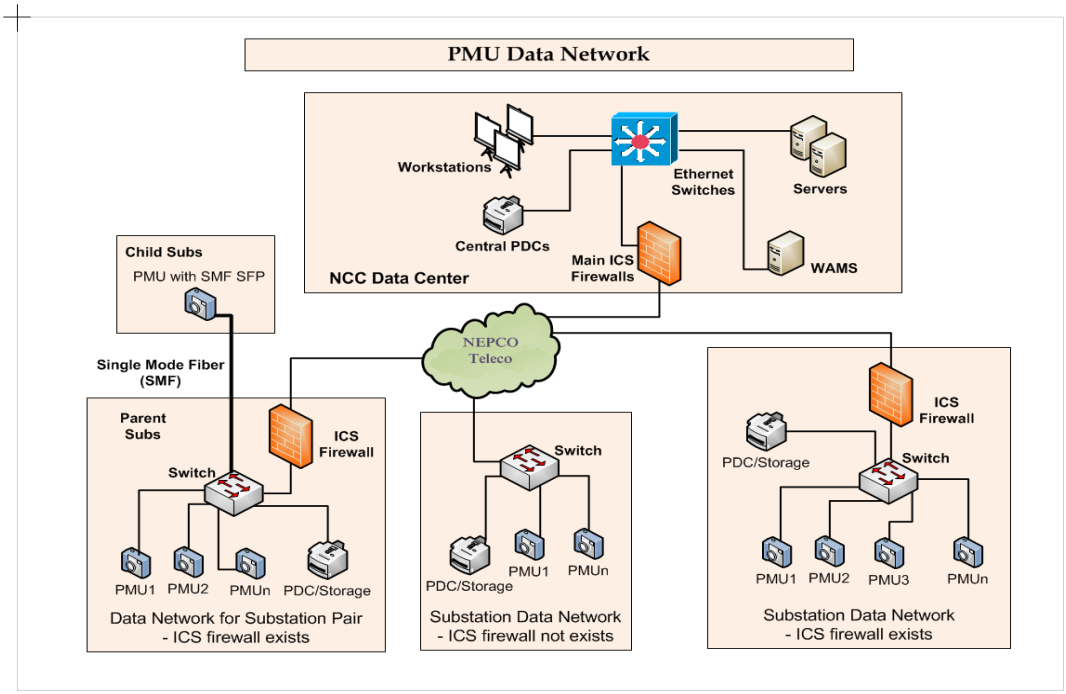
9.2.1 Reference Standards

All PDC components shall be designed and implemented in reference to section 7

9.2.2 Network Integration and WAMS Architecture

PMU synchrophasor data is streamed to local and /or central PDCs located at NCC center. WAMS are equipped with the required software to permit the visualization and analysis of synchrophasor data.

The Bidder/Contractor shall be aware that the offered PDCs must support a seamless integration with PMUs, other PDCs and WAMS applications servers. A conceptual high-level architecture of the WAMS system to be implemented at NEPCO is shown in the following figure.



Note:

NEPCO works in another project to enhance the cybersecurity standing of the substations through securing communication of existing automation and control systems with substation by using ICS firewalls. The ICS firewalls will be installed in substations to segregate the local data network of each substation and provide protection for various power systems including PMU project. The supplied data network of the PMU in each substation will be connected to either telecom or to the planned ICS firewall.

9.2.3 Functional Requirements

a. General Functional Requirements

The data shall be stored locally even by PMU or Local PDC for at least 5 days, where if PMU communicates with a PDC (Local) the PDC shall provide the following functions in compliance with IEEE C37.244-2013 guide for phasor data concentrator requirements for power system protection, control, and monitoring:

- Data aggregation;
- Data forwarding;
- Data communications;
- Data validation;
- Data time –alignment
- Data transfer protocol support;
- Data transfer protocols conversion;
- Data format and coordinate conversion;
- Data latency calculation;
- Reporting rate conversion;
- Output data buffering;
- Configuration;
- Phase and magnitude adjustment for calibration;
- Performance monitoring;
- Redundant data handling;
- Duplicate data handling;
- Data re-transmission request;
- Retrieval of archives based on time and date, manually or automatically.
- Receiving synchrophasor measurements simultaneously from multiple PMUs or other PDCs in compliance to IEEE C37.118 format, via TCP and UDP protocol for unicast and multicast reception of data.

- Sending fully configurable output data streams simultaneously to multiple internal and external clients at variable reporting rates including 10, 25 and 50 frames per second for a 50Hz system.
- Support for a variety of output formats, communication protocols and flexible data interface requirements with external host applications including IEEE C37.118, IEC 60870-5-104, IEC 61850-90-5 and Modbus and DNP protocols. The PDC shall support TCP and UDP protocol for unicast and multicast transmission of PDC data.
- Communicate with PMUs, Central PDCs of the same or different manufacturers using appropriate protocols. Interoperability and seamless integration shall be ensured.
- Support for redundant input and output connections, with failover capability switching to a backup connection whenever the quality of the primary connection is low.
- Mathematical calculations such as active and reactive power, positive, negative and zero sequence components and parameters scaling. If not available in proposed PMUs.
- Programmable logic including user configurable logic blocks and timers to support autonomous WAMS control and protection applications.
- Storing, reporting and archiving of synchrophasor data, calculated data, sequence of events (SOEs), alarms and triggering events to the PDC's built-in solid-state drive (SSD) for short-term storage.
- The recoded data, SOEs and events will be archived to external central data storage server in NCC for long-term archiving in database format.
- The PDC shall support both continuous and event-driven archiving.
- Furthermore, it shall also be possible to perform data queries through the Structured Query Language (SQL) or OPC-UA. The PDC shall also support data export function from the database in Comma Separated Value (CSV) and COMTRADE format.
- User-friendly tool for configuration including communication settings, input/output settings, phasor data filtering, logic and data calculation, mapping, parameters scaling and data archiving.
- User-friendly tool for performance monitoring, commissioning and troubleshooting of PDC and the PMUs reporting to it.
- Users shall be able to monitor the overall system operation and the communication with other PMUs and PDCs in real-time including devices status, inputs and output streams status, system errors, data quality (e.g. error counters), and communications statistics and diagnostics (e.g. latency).
- User accounts management for access control, activity logs and reporting. It shall be possible to configure different user's access groups such as admin, engineer and operator.
- High performance, adaptability and scalability for integrating additional phasor data streams from future PMUs deployment.

- Cyber security features for compliance with international industry standards.

b. Central PDCs Requirements

In addition to the PDC general functional requirements listed above, the following requirements shall be considered for Central PDCs installed at NEPCO's NCC:

- Online/hot-standby operation approach through seamless switchover.
- Have a minimum of 3 output data streams, and not less than 20 number of input data streams. And the number of offered input and output streams shall be adequate for this project.
- The central PDC shall be scalable allowing for future expansions with no license limitations for adding additional input and output data streams.
- The Bidder/Contractor shall provide details and calculations of hardware capability to support the current installation as well as future expansions, e.g. processing power, memory, etc.
- Data archiving to an external standalone long-term data storage server for data analysis and assessment for a minimum of 1 year.
- Expanding the central PDC internal storage shall be possible if additional storage space is required.
- Storage synchronization shall be maintained between the two central PDCs within control center.
- It shall also be possible to export the data in COMTRADE and CSV format
- In case of a communication link failure to another PDC, the PDC shall buffer the data until a reliable connection is restored. Once the connection is restored, the data shall be seamlessly restored to the destination PDC.
- PDCs shall operate in high availability approach. If one member is lost, the other member shall seamlessly work without any disruption.

9.2.4 SCADA/EMS Integration

The Central PDC shall have the capability to be integrated with the conventional SCADA/EMS system at NEPCO. It shall be possible to display specific WAMS data and be notified of alarm conditions once they occur through the SCADA/EMS displays pages.

The integration shall be platform-independent and shall enable data access from different SCADA/EMS systems. To facilitate the integration, the central PDC shall be capable of scaling down the reporting rate of WAMS data before transmitting it to the SCADA/EMS system.

The integration interface shall support standardized communication protocols such as IEC 60870-5-104, OPC UA, IEEE C37.118 and IEC 61850-90-5.

9.2.5 Software Requirements

A tool for user-friendly engineering, monitoring and data retrieval shall be available. The tool shall also allow remote configuration and firmware upgrade of the PDC.

The offered solution shall ensure OS compatibility with all WAMS components including PMUs sand WAMS applications servers.

In case of popular operating system, the OS shall NOT be outdated software. The available OEM support for operating system software shall endure for at least five years after suppling the material.

9.2.6 Security Requirements

The PDC shall have cyber security features that enable the design of a system in compliance with industry standards for secure handling of the device, including user activity logging, authority handling, user management and system event logging over Syslog to enable a system-wide overview of system events. It shall also have per-port enable/disable capability of engineering access and communication protocols.

The PDC shall comply with international industry standards with a proof of compliance provided.

9.2.7 Hardware Availability

Bidder/Contractor shall state in its offer the PDC server hardware availability while in service i.e. MTBF and MTTR values. Supporting document from the manufacturer shall be enclosed

9.3 Testing & Inspection

9.3.1 General for Testing

All PDC components shall be configured, integrated and tested at the Manufacturer's facilities. The Bidder/Contractor may be required to carry out any or all of the tests stated in this specification under witness of NEPCO or its representatives.

Testing of PDC shall be performed in line with this specification and in accordance with the relevant international standards (as a minimum requirement) and other standards as may be approved by NEPCO.

Acceptance by NEPCO's representatives of PDC shall not relieve the manufacturer from any of its obligations.

NEPCO reserves the right to perform checks during manufacturing process at any time or all the times. It shall be at the discretion of NEPCO to witness tests on 100%, or any percentage quantity of each lot for routine tests, apart from the type tests, wherever called for.

Tests of PDC shall comprise factory and site tests.

9.3.2 Factory Tests

a. Type Tests

Evidence shall be given that the proposed PDC to be supplied under this specification have been subject to all type tests at an internationally recognized testing facility. If deemed necessary.

An internationally recognized laboratory approved by NEPCO shall certify the type test reports.

The Bidder/Contractor shall submit certified copies of type test certificates covering the proposed PDC.

Type tests certificates/reports shall be considered acceptable if they are in compliance with the relevant standards and the following:

- Type Tests conducted at an internationally recognized laboratory acceptable to NEPCO.
- Type Tests conducted at the manufacturer's laboratory and witnessed by representatives from an internationally recognized laboratory acceptable to NEPCO.

If the presented type test reports are not in accordance with the above requirements, NEPCO may decide to ask for the type tests to be carried out in the manufacturer's premises or other places subject to the approval of NEPCO and at no additional cost. These tests shall be performed in the presence of an internationally recognized laboratory, which should issue the relevant type test certificates upon successful test.

The type tests to be performed shall comply with NEPCO specification requirements and shall include tests such as, but not limited to, the following:

- PDC functionalities and performance tests as per the latest IEEE C37.244 guide.
- Electromagnetic Compatibility (EMC) Immunity test.
- Electromagnetic Compatibility (EMC) Emissions test.
- Safety/Insulation test.
- Environmental test.
- Vibration test.

b. **Routine Tests**

Routine Tests shall be performed, comprising, as a minimum, the following tests:

- Visual checks.
- Functional checks.
- Print layout.
- Verification of the communication links.
- Performing a sample of analysis.
- Checking other features, which are inherited by the system.
- Performance testing
- Sizing and capacity testing.
- Installation and integration procedures test.
- Data storage archiving testing.
- Cyber security testing as per international standards such as IEC 62351-100 conformance testing.
- Cyber security testing as corresponding to the proposed cybersecurity aspects
- Verify to Integrate with PMUs and WAMS application
- Performance testing
- Adaptation works (software and hardware) at main WAM application.
- Checking of PMUs and PDCs identification numbers
- Validate the received PMU data and communication latency.
- Examine communication errors and data loss.
- Verify data quality and data status indications.

9.3.3 Site Tests

Site Tests shall be performed, comprising, as a minimum, the following tests:

- Installation checks.
- Performance testing

- Sizing and capacity testing.
- Installation and integration procedures test.
- Data storage archiving testing.
- Cyber security testing as per international standards such as IEC 62351-100 conformance testing.
- Cyber security testing as corresponding to the proposed cybersecurity aspects
- Adaptation works (software and hardware) at NCC.
- Checking of PMUs and PDCs identification numbers
- Validate the received PMU data and communication latency.
- Examine communication errors and data loss.
- Verify data quality and data status indications.
- Compare measured PMU data with SCADA/EMS measurements and confirm they are reporting the same values.

9.4 PDC and WAMS Documentation

PDC and WAMS complete documentation is required to support setup, operation, troubleshooting and maintenance, including the following:

1. Systematically guide for installation and configuration.
2. The user guide includes but is not limited to the following:
   - Adding new PMU to the system.
   - View in detail the functionalities of the system.
   - Build and extract new reports from the system.
   - Troubleshooting manual, including fault scenarios and fixing procedures.
   - System and hardware infrastructure requirements

10. WAMS peripherals (WAMS-per)

10.1 General for WAMS-per

WAMS peripherals refer to all components needed to provide a fully functional WAMS system. These major building blocks, WAMS requires additional components to function correctly

including GPS satellite receivers, servers, storage, software applications and packages, Ethernet switches, routers and firewalls.

This specification covers the design, functionalities, and hardware requirements of WAMS peripherals.

10.2 Technical Description

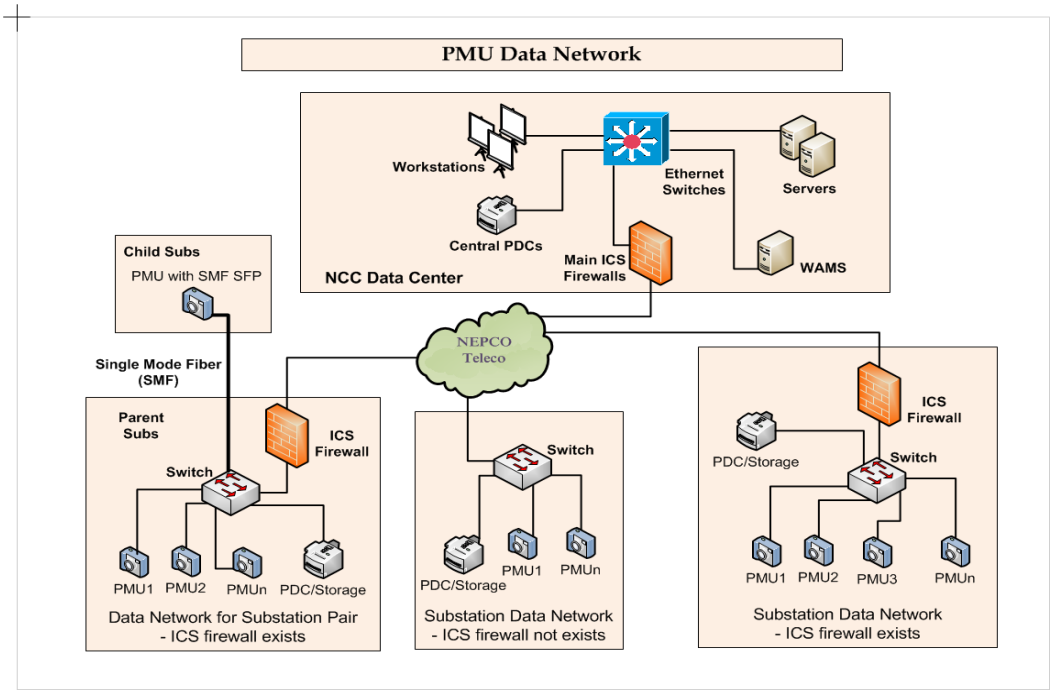
10.2.1 Reference Standards

All WAMS-per components shall be designed and implemented in reference to section 7

10.2.2 Network Integration and WAMS Architecture

PMU synchrophasor data is streamed to local and /or central PDCs located at NCC Center. WAMS master stations are equipped with the required software to permit the visualization and analysis of synchrophasor data.

The Bidder/Contractor shall be aware that the offered WAMS peripherals must support a seamless integration with all WAMS components. A conceptual architecture of the WAMS system to be implemented at NEPCO is shown in the following figure.



10.2.3 Functional and Hardware Requirements WAMS Peripherals

a. Comprehensive GPS System

GPS system operates in redundant configuration shall be offered to provide time synchronisation to PMUs, as well as WAMS peripherals, PDCs, WAMS applications servers, and WAMS workstations. Time synchronization is necessary in order to guarantee a system wide accuracy of time related data. The GPS system shall provide continuous precise timing referenced to UTC with accuracy of at least 1 microsecond. The timing signal shall be accurate enough to keep the total vector error (TVE) of PMU measurements within the limits defined in IEEE C37.118.1a-2014 standard. The GPS receiver shall also provide an indication of traceability to UTC and leap second changes.

The bidder shall propose proved design for GPS system that may consist of several variant GPS units/modules across project locations (NCC and substation). The proposed design shall meet the required time accuracy, and system availability to guarantee time synchronization for all supplied components across project locations.

Time distribution can be achieved from the GPS system through IRIG-B, NTP, PTP and 1PPS as needed. Moreover, the GPS receiver shall offer network redundancy by supporting Parallel Redundancy Protocol (PRP).

The GPS system shall be housed in a 19" standard frame. Multiple BNC outputs and at least one DB-9 port shall be provided for IRIG-B or time pulse distribution, as well as multiple 1000Base-TX Ethernet ports for NTP or PTP distribution.

The receiver shall have an alarm output contact to report GPS receiver failure alarm. Furthermore, the receiver shall have a redundant power supply supporting 110VDC with (+15%, -20%) tolerance for substation installations and 230VAC at 50Hz with ±10% tolerance for NCC installations. Antennas, cable and surge arrestors must be included.

The bidder shall clearly submit the complete design for GPS system supported with obvious drawing that displays the locations of the proposed GPS components and the used time distribution protocols.

b. Ethernet Switches in substation

The number of the Ethernet ports shall be adequate to connect the provided devices (like PMU, PDC, and GPS/NTP).
Additional four Ethernet ports in Ethernet switches in each substation shall be considered. The additional Ethernet ports will be used for:

- One Ethernet port as an uplink to connect the supplied data network to telecom equipment in a substation
- Three Ethernet ports will be free for future use.

The supplied Ethernet switches shall be featured with the following characteristics:

- The switches form factor is appropriate to be mounted inside the PMU cabinets
- Gigabit Ethernet ports
  High-performance appliances, wire-speed non-blocking forwarding
- Support IEEE 802.1Q with 4,094 simultaneous VLAN IDs.
- Layer 3 routing: dual-stack, InterVLAN routing, Static and dynamic IP routing.
- Support IEEE 1588 Precision Time Protocol (PTP) version 2 and shall be PTP-aware
- Support RADIUS
- IEEE802.1x port access control with EAP, PEAP, EAP-FAST
- Control plane security/protection
- 802.1x Multiple supplicants
- 802.1x Enterprise mode: RADIUS/TACACS, EAP
- L2 security features: MAC filtering/restriction, DHCP snooping, Dynamic ARP inspection (DAI), IP source guard
- Provides IP Layer 2 to Layer 4 traffic filtering; supports global ACL, VLAN ACL, port ACL, and IPv6 ACL
- Data telemetry: IPFIX/NetFlow/sFlow, SNMPv2/3, SNMP trap, Syslog TCP/UDP/TLS
- Management: OOB TCP/IP port, console, SSHv2, HTTPs, PTP, NTP, SCP, LLDP, GVRP, local and server-based authentication
- Integrated (internal) 110V AC/DC redundant power supplies (Power supply must operate by DC power at substations sites as NEPCO policy recommendation)

c. Substation Pairs

NEPCO will use one telecommunication connection for each pair. The substation providing the telecommunication Metro-Ethernet port is called the parent substation, and the other member is called as child substation.

There will be a single-mode dark fiber between the parent and the child for each pair to connect the PMU units in the substation pair and PDC if exists. The fiber will be connected to appropriate SFPs inside either an Ethernet switch or inside the PMU unit in the child substation; the choice depends on the number of PMU units in the child substation. The fiber will be connected to Ethernet switch at the parent substation through appropriate SPF. The SFPs shall be the single-mode fiber of 1 Gbps and shall consider the distance between the members of each substation pair. Copper-to-fiber converters will be rejected.

The substation pairs are the following:

1- Queen Alia 132 (parent) and Queen Alia 400 (child), distance is around 1 km

2- Amman North 132 (parent) and Amman North 400 (child), distance is around 1 km

3- Aqaba (ATPS) 400 (parent) and Aqaba industrial (AI) 132 (child), distance is 30 km

4- Samra 400kV (parent) and Samra 132kV (child), the distance is greater than 4 kilometer.

d. Main Ethernet Switches in NCC

Two Ethernet switches operating in high available (HA) modes in order to connect provided WAMS peripherals such as servers, main firewalls, central PDCs. It shall provide reliable, fault-tolerant and secure TCP/IP connections.

- 24 RJ45 autosensing 10/100/1000 ports, Auto MDIX, Auto-negotiation.
- Two 1000Base-LX ports with equipped the single mode SPFs to connect the provided access Ethernet switch
- Standard 19" rack-mountable with all required equipment.
- Wire-speed non-blocking forwarding.
- Adequate throughput, the bidder shall consider near future expansion about (200%)
- True Stacking (support cross-stack trucking, VLANs, QoS and unified configuration with single IP address management across all stack members).
- Supports IEEE 802.1Q with 4,094 simultaneous VLAN IDs.
- Layer 3 routing: dual-stack, Static IP routing, dynamic routing Protocols.
- Routing table size 512 entries (IPv4), 256 entries (IPv6)
- 220 V AC power supply
- Data telemetry: IPFIX/NetFlow/sFlow, SNMPv1/2/3, SNMP trap, Syslog TCP/UDP/TLS
- Management: OOB TCP/IP port, console, Telnet, SSHv2, HTTPs, PTP, NTP, SCP, LLDP, GVRP, local and server-based authentication
- Support IEEE 1588 Precision Time Protocol (PTP) version 2 and shall be PTP-aware
- Spanning Tree Protocols: STP, RSTP, MST
- IPv4/IPv6 Multicast: IGMPv1/2/3, IGMP snooping, IGMP filtering, multicast routes and groups
- LACP different load sharing Algorithms: Source/Destination - MAC/IP/TCP/UDP
- Security features:
  - Port access control (802.1x)
  - 802.1x Multiple supplicants
  - 802.1x VLAN with assignment
  - 802.1x Enterprise mode: RADIUS/TACACS, EAP
  - MAC filtering/restriction
  - Dynamic ARP inspection (DAI)
  - DHCP snooping
  - IP source guard
  - BPDU and root STP filtering/protection
  - Port-based unicast/multicast/broadcast storm control

  - Control plane security/protection
  - provides IP Layer 2 to Layer 4 traffic filtering; supports global ACL, VLAN ACL, port ACL, and IPv6 ACL
- Temperature sensor & Fan monitoring.
- Quality of Service:
  - Broadcast control, classification based on Layer 2, 3, and 4 information
  - QoS policies based on port or VLAN.
  - Congestion actions: Strict Priority (SP) queuing, Weighted Round Robin (WRR), and SP+WRR.
  - Traffic policing: supports Committed Access Rate (CAR) and line rate

e. Access Ethernet Switch

The bidder shall provide a layer 2 Ethernet switch to connect workstations that are located remotely. The provided switch shall from the same vendor of the provided main Ethernet switches, and it contains 8x10/100/1000 Ethernet ports with 2x1000Base-LX SPFs. The two 1Gbps LX SPFs shall be supplied.

This switch shall be enterprise-class similar to the provided NCC Ethernet switches and incorporate comparable main Layer2, data telemetry, management, and security features required in the NCC Ethernet switches and 220 AC power supply.

f. Routers

Two routers are required to connect PMU IP network in one of the NEPCO substations, Risha substation, to WAMS applications IP network in NCC. The routers are required for Risha substation according to the available telecom interface which is G.703, where is no Metro-Ethernet connection as exits in the other substations. The routers shall meet the minimum following specifications:

- 19-inch Rack-mounted device
- Equipped Ports: One 1000Base-TX LAN interface, one channelized G.703 T1/E1 WAN interface with RJ45 connector, serial console port
- Data telemetry: IPFIX/NetFlow/sFlow, SNMPv2/3, SNMP trap, Syslog TCP/UDP/TLS
- Layer 3 routing: dual-stack, Static and dynamic IP routing.
- Advanced security capabilities
- Security policies elements: Layer 3 and Layer 4 information

- Management: OOB TCP/IP port, console, SSHv2, HTTPs, PTP, NTP, SCP, LLDP, local and server-based authentication
- Shall be PTP-aware
- 110-V AC/DC (+15%, -20%) redundant power supplies (Power supply must operate by DC power at substations sites as NEPCO policy recommendation)
- For the router in Risha substation, it acceptable to offer appropriate Ethernet switch module into the proposed router instead of dedicated switch.

g. Main ICS Firewalls

The two main ICS firewalls will be installed in NCC, it will work as one firewall for high availability, and it will provide protection for the provided applications, WAMS, WAMS peripherals, PMUs communication, workstations, and network control access. The firewalls shall NOT form a single-point of failure and it shall work in high availability behavior.

Firewalls support application visibility (recognition) and control for IT and OT services, provides control and analysis of the industrial protocols guarantees the detection and protection of the electrical power and IT applications. It shall have the following capabilities as a minimum:

- 19" rack-mounted appliance(s)
- Adequate device throughput, the bidder shall consider near future expansion about (200%)
- Gigabit Ethernet ports, additional free Ethernet ports shall be considered (at least four ports)
- Failover ports, as well as OOB management ports, shall be included.
- High-performance appliances IT and OT threat detection, anomaly detection capabilities and automatic attack prevention (DoS/DDoS, address spoofing)
- Support IEEE 1588 Precision Time Protocol (PTP) version 2 and shall be PTP-aware
- Strengthen the security level on the OT network and conduct a thorough inspection and control of the traffic
- Security policies elements: source/destination, user/group, Layer 4 port numbers, Application/micro-application, industrial protocol data/command/configuration commands
- Interoperable with SIEM/SOC solutions

- Can be fully managed through a centralized management solution
- Shall support VRFs
- The ICS firewalls shall support and include the following industrial protocols as a minimum:
  - IEEE-C37.118-Synchrophasor (variant versions)
  - MMS-ICS
  - IEC60870-5-104
  - IEC61850-9-50 (Preferred)
  - OPC UA, OPC (DA/HDA/AE)
  - Any industrial protocol that is incorporated in this project
- Data telemetry: IPFIX/NetFlow/sFlow, SNMPv1/2/3, SNMP trap, Syslog TCP/UDP/TLS
- Accomplish traffic capture and can be exported in a universal format
- Management: OOB TCP/IP port, console, Telnet, SSHv2, HTTPs, PTP, NTP, SCP, LLDP, GVRP, local and server-based authentication
- Authentication: Active directory, MFA, local
- Required license shall be provided; for the annual license, it shall be for three years.

h. Antimalware

The bidder shall propose a verified antimalware security solution to protect endpoints provided in this project.

The required solution is needed to secure the PMU system relevant components using popular operating systems to ensure maximum protection against malware and suspicious activities. As well as maintain strict control over any changes to the system OS and applications.

The antimalware shall have the following capabilities:

- Provide protection for the supplied endpoints (servers, workstations, PDCs if applicable) without affecting the functionalities of the running application
- Works in numerous ways: signature-based, behavior-based, proactive threat blocking, signature less payload analysis and anomaly detection
- Zero-day attacks prevention
- Application control
- USB control
- Support online and offline update
- Update for the endpoint from the central management can be achieved automatically or manually
- Detect and investigate suspicious activities

If needed for the centralized security center platform, the relevant hardware/VM shall be supplied.

i. System and hardware infrastructure requirements

The proposed design for the WAMS/PMU system in NCC should highly consider the redundancy approach based on secure, scalable, high available, fault tolerant, and high performance architecture. The proposed architecture shall enable NEPCO to collect, process, store, retrieve, archive, visualize, user access synchophasor data, SOEs, events and relevant data. All hardware, software and licenses components of the proposed architecture shall be provided.

The supplied servers and the related storage shall meet the requirements to operate the supplied solutions such as WAMS, archived data and events, management solution and supplied software operated in the NCC data center.

- The provided WAMS-per hardware shall be replaceable with no license restriction to hardware, which means it is possible to replace provided hardware without losing provided system functionalities.
- The proposed WAMS applications shall be implemented in a way that provides some availability or failover either by utilizing some sort of active/standby mechanism if it is applied by the proposed software or by utilizing any kind of virtualization technology, the bidder shall choose the cost-effective solution according to best practices and mother company documentations.
- All proposed server(s) to operate WAMS applications shall have a minimum of adequate numbers of RAID1 SSD disks for the operating system(s). And adequate numbers of RAID5 or RAID6 disks for the application data. The size of these disks fully depends upon the sizing calculation performed by the bidder.
- All hardware devices (servers, storage,.. etc.) needed to install and operate the proposed WAMS applications shall be sized accurately in a cost-effective manner and to maintain the availability of the system in case of single item hardware failure and to support (200%) additional expansion in the future with proposed setup without additional hardware or software expansion.
- All proposed equipment shall have redundant components to prevent disruption to equipment or communications in case of single component failure. Such components are CPU’s Socket, Memories and Banks, Disk Drives, Fans, Power supplies, Network adapters, Storage controllers, etc.

- All proposed hardware devices shall have a dedicated management port with an advanced and full management license to remotely administer and manage the device.
- All devices shall be rack-mounted and delivered with all required rack kits, sliding rails, cable management arms, and accessories.
- If needed, all devices shall be delivered with all SFP+ transceivers and fiber/copper cables required for communications and to deliver extra required transceivers for the switches.
- The bidder shall provide a KVM 19" LCD with 8x ports KVM switch with all adapters and accessories to cover the number of ports and connect the proposed hardware.
- The bidder shall deliver all software licenses (operating system, virtualization, database) required to operate the equipment, install and run the WAMS monitoring solution.
- Any supplied operating system, virtualization hypervisor, software applications shall be **NOT** outdated, the OEM support shall endure for at least five years.
- The bidder shall provide an antimalware compatible list for WAMS and other provided Windows-based systems/workstations
- The bidder shall provide the following:
  - A detailed design and implementation document for the proposed solution.
  - A detailed hardware specification for the proposed equipment.
  - BOQ table describes the quantities of all proposed hardware devices
  - Any third part or open source software being used or implemented in this project shall be listed.

j. Server/Network Cabinet minimum specifications

The required cabinet will be used to mount the supplied hardware in NCC, with the following specifications:

- 42U freestanding.
- Heavy duty.
- Dustproof.
- On-roof cooling fan tray with a min of 4-fans.
- Button cable openings with removable cover cable entry
- Plexiglas front door.
- Removable and Lockable doors and sides/back panels
- One 12-way horizontal rack-mounted PDU suitable for power cords of supplied servers.

- PDU should be equipped with a Suitable circuit breaker
- Fiber and UTP patch panels
- Cable organizers
- Suitable Lighting
- Castor kit
- Levelling feet kit
- Grounding kit
- Full-depth fixed shelf (for monitor, keyboard and mice).

Total/Internal depth/width should be compatible with provided equipment.

10.2.4 Service Conditions

Components used as WAMS peripherals shall be capable of operating in ambient temperatures from -10° C to +50° C with a maximum ambient relative humidity of %77.

10.2.5 Hardware Availability

Bidder/Contractor shall state in its offer the WAMS peripheral availability while in service i.e. MTBF and MTTR values. Supporting document from the manufacturer shall be enclosed.

10.3 Testing & Inspection

10.3.1 General for WAMS-per

All WAMS peripherals shall be integrated and tested at the Manufacturer's facilities. The Bidder/Contractor **may be** required to carry out any or all of the tests stated in this specification under witness of NEPCO or its representatives.

Testing of the WAMS peripherals shall be performed in line with this specification and in accordance with the relevant international standards (as a minimum requirement) and other standards as may be approved by NEPCO.

Acceptance by NEPCO's representatives of any WAMS peripheral shall not relieve the manufacturer from any of its obligations.

NEPCO reserves the right to perform checks during manufacturing process at any time or all the times. It shall be at the discretion of NEPCO to witness tests on 100%, or any percentage quantity of each lot for routine tests, apart from the type tests, wherever called for.

Tests of WAMS peripherals shall comprise factory and site tests.

10.3.2 Factory Tests

a. Type Tests

Evidence shall be given that the proposed WAMS peripherals to be supplied under this specification has been subject to all type tests at an internationally recognized testing facility. If deemed necessary, NEPCO will decide whether additional tests shall be performed by the Bidder/Contractor.

An internationally recognized laboratory approved by NEPCO shall certify the type test reports.

The Bidder/Contractor shall submit certified copies of type test certificates covering the proposed WAMS peripherals.

Type tests certificates/reports shall be considered acceptable if they are in compliance with the relevant standards and the following:

- Type Tests conducted at an internationally recognized laboratory acceptable to NEPCO.
- Type Tests conducted at the manufacturer's laboratory and witnessed by representatives from an internationally recognized laboratory acceptable to NEPCO.

If the presented type test reports are not in accordance with the above requirements, NEPCO may decide to ask for the type tests to be carried out in the manufacturer's premises or other places subject to the approval of NEPCO and at no additional cost. These tests shall be performed in the presence of an internationally recognized laboratory, which should issue the relevant type test certificates upon successful test.

The type tests to be performed shall comply with NEPCO specification requirements and shall include tests such as, but not limited to, the following:

- Electromagnetic Compatibility (EMC) Immunity test as per the latest IEC-60255.
- Electromagnetic Compatibility (EMC) Emissions test as per the latest IEC-60255.
- Safety/Insulation test as per the latest IEC-60255-5.
- Environmental test as per the latest IEC-60068.
- Vibration test as per as per the latest IEC-60255-21.

b. Routine Tests

Routine Tests shall be performed, comprising, as a minimum, the following tests:

- Visual checks.
- Functional checks.
- Print layout.
- Verification of the communication interfaces and communication links.
- Test of clock synchronization by GPS system.
- Checking other features which are inherited by the system.
- Performance testing
- Sizing and capacity testing.
- Installation and integration procedures test.

10.3.3 Site Tests

Site Tests shall be performed, comprising, as a minimum, the following tests:

- Installation checks.
- Verification of the communication interfaces and communication links.
- Test of clock synchronization by GPS system.
- Performance testing
- Sizing and capacity testing.

10.4 Installation/backup/restoration test. Documentation

The bidder shall provide a full system installation and configuration document which includes a detailed step by step description of the following:

- Network and data layout for the overall system and hardware infrastructure.
- Configuration of the management ports on all proposed hardware.
- Installation and configuration of the operating system and system software.
- Installation and configuration of the shared storage and other proposed hardware.
- Installation and configuration of the WAMS.

- Guideline for implementing system backup and archiving WAMS and PDCs data (how to).
- Installation and configuration of all proposed equipment such as PMUs, GPS Clocks…etc.
- System user manuals
- System technical manuals
- Equipment / system instruction manuals

All documents should be presented in English.

11. WAMS Applications

11.1 General for WAMS Application

WAMS applications refer to the visualization and data analysis tools, and other advanced WAMS applications that typically reside within the WAMS Master. WAMS Master is one of the major building blocks of a WAMS and consists of the WAMS applications servers, clients and workstations.

WAMS applications transform the collected synchrophasor measurements into actionable items for the system operators and engineers. In addition to basic visualization and data analysis tools, advanced WAMS applications will help realize the full potential of WAMS. Advanced WAMS applications are classified into real-time and offline applications. Real-time applications can be employed for the minute-by-minute power system operations, while offline applications are used for power system studying and to analyze disturbances and system behaviors. Examples of real-time applications include oscillation detection and monitoring, voltage stability monitoring, and phase angle monitoring. Offline applications, on the other hand, include applications such as post-mortem analysis, model validation and calibration and renewable resource integration.

All WAMS applications including visualization, data analysis tools, and advance real-time and offline WAMS applications shall be available at NCC center. At the substations level, no WAMS applications are required. However, provision shall be made to allow future addition of WAMS workstations for visualization and data analysis.

This specification covers the design, functionalities, hardware requirements, factory testing, installation, on-site testing and commissioning of WAMS applications.

The specification also provides NEPCO’s functional and performance requirements for WAMS applications.

This specification covers the following WAMS applications:

- Basic visualization and data analysis tools:
  Wide-area visualization and monitoring of key system parameters measured by PMUs or PDCs in real-time, and post-event offline analysis of system disturbances using historical data.

- Advanced WAMS applications:
  - Real-time applications:
    - Oscillation detection and monitoring;
    - Phase angle monitoring;
    - Voltage stability monitoring;
    - Islanding detection, management, and restoration;
    - Event detection and management;
    - Equipment problem detection;
    - Wide-area control and protection.
    - Inertia monitoring
    - Sub synchronous resonance (SSR)
  - Offline applications:
    - Post-event analysis;
    - Model validation and calibration; and
    - Renewable resource integration.
- WAMS are equipped with the required software to permit the visualization and analysis of synchrophasor data.
- The Bidder/Contractor shall be aware that the offered WAMS applications and hosting servers at NCC must support a unified integration with all PMUs and PDCs in the WAMS network.

11.2 Reference Standard

All WAMS applications components shall be designed and implemented in reference to the related standards in section 7.0

11.3 Functional Requirements

a. General Functional Requirements

WAMS applications including visualization tools, data analysis tools, and advanced WAMS applications shall reside on a dedicated physical/virtual server(s) called the WAMS applications server(s). WAMS applications shall be able to access all data collected or generated via the PDC, including PMU data, calculations and alarms. At the same time, WAMS applications data, calculations and alarms shall also be available into the WAMS server(s). WAMS applications shall be able to access and retrieve archived data, whether stored internally, in the PDC. It shall be possible to store data, calculations, graphs, charts, and reports generated by the WAMS applications. It shall be possible as well to select between continuous synchrophasor data archiving or event driven data archiving, with a variable data archiving rate.

WAMS applications data, calculations and alarms shall be available for integration into the existing SCADA/EMS system. An example would be to display an alarm notification on the

SCADA/EMS displays when an inter-area oscillation mode is detected via WAMS applications. Furthermore, it shall be possible to include WAMS applications data, calculations and alarms in the output data streams sent.

As NEPCO is adopting a staged strategy in implementing WAMS applications, the offered solution shall be scalable with the ability to implement additional applications in the future. The offered solution shall also enable NEPCO engineers to develop user-defined functionalities and customized tools to address more advanced applications such as wide-area control and protection.

At the same time, the offered solution shall be delivered with a software package for NEPCO's engineers and planners to run in-depth offline analysis and planning studies by leveraging WAMS historical data.

b. Visualization and Data Analysis Tools

The offered solution shall include basic visualization and data analysis tools to enable real-time monitoring of measured and calculated values, and offline analysis of system disturbances using historic data. The following functionalities shall be supported as a minimum:

- The bidder shall provide the license requirements for the WAMS monitoring solution based on solution client access methodology.
- Single line overview of the power system and a multilayered geographical map showing measured and calculated values such as voltages, angle differences, and frequencies. If available, the overview or map shall also indicate events from advanced WAMS applications such as detected oscillations, Inertia Estimation, islanding conditions and location of limit violations.
- If needed, WAMS application shall be capable to import the GIS maps of various digital format (base, geographical, …) through various methods; online API or manual import
- Trending displays of voltage and current magnitudes and angles, frequency, Rate of Change Of Frequency (ROCOF), real and reactive power values for real-time monitoring and post-disturbance analysis. The displays shall be available to all data collected or calculated by the PDCs or any of the WAMS applications. The displays shall also provide options like axis scaling, adjusting time scope, zooming, rulers, etc. It shall be possible to save and print any of the displays.
- Polar chart showing angles of single phase or three phase quantities compared to a reference angle.
- A panel for alarms and events providing notifications of all alarm conditions and user-defined events. The user shall be able to set thresholds on any of the measured or calculated values to trigger alarms.
- Mathematical calculations including active and reactive power, positive, negative and zero sequence components and parameters scaling.

- User-defined programmable logics to support the development of customized WAMS functionalities and applications such as automated wide-area control and protection applications.
- Import functionality of historic data using Comma Separated Value (CSV) and COMTRADE formats.
- Option to enable a replay mode for analysis of critical incidents that have happened. During this mode, measurements and events from the selected time window shall be shown on all displays, charts and graphs, without losing real-time PMU data streams.
- Ability to produce customized reports using historic data and the data analysis tools.
- System health indication including the condition and communication status of all PMUs, PDCs, databases, and output data streams.
- System specific logs with filtering and export capabilities.
- Data export functionality of raw WAMS data and data generated by WAMS applications using configurable CSV and COMTRADE formats to an internal or external database. It shall also be possible to export all calculations, reports, charts and graphs generated by WAMS applications.
- User-friendly tool to configure user interface, application parameters and settings, reports content, alarm thresholds, user accounts, etc.
- Access control via user accounts management including activity logs and reporting. It shall be possible to configure different user access groups such as admin, engineer and operator.

Cyber security features for compliance with international industry. At the same time, it shall be possible to define all of the following alarm conditions as a minimum:

- Deviation from nominal frequency;
- ROCOF exceeding a set value;
- Voltage magnitude outside upper or lower boundaries;
- Current magnitude outside upper boundaries;
- Phase angle differences of voltage or current outside limits;
- Active or reactive power exceeding limits;
- Voltage angle difference between selected points exceeding limits;
- WAMS Application events such as detected power oscillations, islanding conditions, voltage instabilities, equipment failure and the detection of generation or demand loss; and
- System health events such as communication error with PMUs, PDCs, or databases, PMU data quality, PMU time synchronization, etc.

The above mentioned functionalities shall be available to all WAMS user interface workstations.

11.4 Advanced WAMS Applications

The offered solution shall also offer real-time and offline advanced applications modules to realize the full capability of WAMS and allow further analysis of synchrophasor data.

Advanced WAMS application modules shall support import functionality of historic WAMS data for offline and post-mortem analysis, as well as export functionality of all calculations, reports, charts and graphs generated by the applications to internal or external databases. The application modules shall support configurable CSV and COMTRADE formats data imports and exports.

It shall be possible as well to integrate any of the application modules several times at different locations with different application configurations, as well as the ability to integrate the same application at the same location as a new instance.

11.4.1 Real-time Applications

1. Oscillation Detection and Monitoring

The objective of the oscillation detection and monitoring application will be to improve the power system visibility and provide system operators with immediate awareness of oscillation events in the power system via the detection and identification of various oscillation modes.

The application shall quickly identify the frequency, amplitude and damping level of each oscillation mode. The operator shall therefore be able to distinguish local oscillation modes from inter-area oscillation modes by knowing the oscillation frequency. The application shall also characterize the damping behaviour of each mode to help provide an effective early warning before a disturbance in the power system triggers instability, especially for the already known and existing oscillation modes.

The application shall enable the identification of oscillation modes and their damping level during large disturbances and switching events in the power system, as well as during normal ambient conditions.

In cases where power transfer between two areas is limited due to inadequate damping, the application is expected to help with maximizing the power transfer by providing a faster and more accurate view of the current situation than what can be obtained via offline dynamic simulations.

The application shall also characterize the observability of each oscillation mode at the various measurement points. The system operators will therefore be able to identify which components of the power grid are contributing to the oscillation, which will help in identifying the root cause of the problem and determine the necessary actions to improve the damping in these modes.

The applications shall also provide the capability to set individual user-defined warning and alarm levels to notify system operators of oscillations in real-time.

For analysis of past oscillation events, it shall be possible to access historical data in the history database. It shall also be possible to export analysis results via CSV and COMTRADE file formats.

The application shall support the integration of applications data and alarms into the SCADA/EMS system and displays.

2. Phase angle monitoring

This application utilizes PMU measurements to monitor phase angle difference between the two ends of a transmission line. Phase angle difference is important to understand the loading of transmission corridors and the extent to which the system is stressed. This application shall support the following functionalities:

- Display of phase angle difference and the maximum acceptable phase angle difference between selected locations in real-time;
- Display of the phase angle curve at selected locations as a trend; and
- Online warning and emergency alerting.

3. Voltage stability monitoring

The voltage stability monitoring application shall help system operators understand the proximity of the system to its voltage stability limit, and be able to detect voltage problems in time. The application shall utilize PMU measurements from the two ends of a transmission corridor to deliver the dynamic current and voltage phasors with calculated values such as active and reactive power as well as the power flow direction to keep operators always informed about the current voltage stability situation. This application shall support the following functionalities:

- Display of PV-Curve with indication of the actual loading point;
- Calculation and display of actual power margin;
- Display of the voltage and current phasors at both ends of the transmission corridor;
- Display of natural loading point and nominal loading point;
- Display of the actual active and reactive power flow;
- Display of the direction of the active power transmitted through the corridor;
- Display of the equivalent impedance of the load area;
- Data logging and trend display; and
- Online warning and emergency alerting.

4. Islanding detection, management, and restoration

Islanding detection, management, and restoration application shall detect which part of the power system is isolated from the rest of the grid creating an island. The application shall help system operators manage the situation as it happens, and be able to resynchronize the island and restore its connection to the grid. The islanding detection shall be possible via three different selectable ways:

a) Static island detection: If the difference in frequencies is getting larger than a certain limit, then an island state is detected.

b) Dynamic island detection: If the rate of change of frequency (ROCOF) between at least two neighboring values is getting larger than a certain limit, then an island state is possibly present or is in the process of arising.

c) Phase angle: If the maximum phase angle difference of all configured voltage phasors exceeds a certain limit, a network split is assumed.

This application shall support the following functionalities:

- Islands shall be marked with colored areas representing the islanded region in the geographical map;
- Display of difference in frequencies and rate of change of frequencies (ROCOF), and the maximum angle difference of all configured voltage phasors;
- Data logging and trend display; and
- Online warning and emergency alerting.

5. Event detection and management

The event detection and management application shall provide an early indication of grid stress by monitoring abnormal voltage levels, phase angles, frequencies, and power flows. The application shall detect events affecting the normal operation of the system such as transmission line or generator tripping identify fault location and monitor how the system is reacting to the event. The application shall act as a decision support tool to system operators by diagnosing the emerging event and recommending the proper mitigation measures. The application shall therefore support the following functionalities:

- Display of high-resolution graphs of the anomalous power measurement waveforms;
- Display of diagnosed events and recommended mitigation measures;
- Data logging and trend display; and
- Online warning and emergency alerting.

6. Equipment problem detection

Using synchrophasor data, system operators shall be able to identify equipment health issues and mis-operations. The equipment problem detection application shall help system operators diagnose malfunctioning equipment and as a results schedule equipment maintenance or replacement in a non-emergency and organized way that is safe and cost effective. The application shall also expedite the diagnoses of equipment failure to near-real-time, and offer control room staff the ability to offer solutions in minutes rather than hours.

7. Wide-area control and protection

Implement wide-area control and protection applications such as Special Protection Schemes (SPS), and use PMU data to provide wide-area feedback signals in real-time, enabling adaptive protection schemes and a more effective response with wide-area impact.

8. Inertia Estimation

Inertia estimation plays a crucial role in ensuring the reliable and secure operation of power systems. WAMS have emerged as a valuable tool for online inertia estimation, providing real-time measurements and accurate information about system dynamics. WMMS shall enable operators to monitor and manage the system effectively, especially in the presence of renewable energy sources.

The importance of online inertia estimation for operators cannot be overstated. Inertia refers to the inherent resistance of a power system to changes in frequency, and it is a critical parameter for maintaining system stability.

Moreover, WAMS shall have the capability to estimate multi-inertia for multi-area systems. In interconnected power systems, different regions or areas may have distinct inertia characteristics due to variations in generation mix and network topology. PMUs placed strategically across these areas can capture the dynamics and interactions between them. By analysing the phase angles and frequencies measured by these PMUs, operators can estimate the inertia of each area and assess the system's overall inertia response.

WAMS shall be assisted in estimating hidden inertia due to unknown renewable energy injected at the distribution level. As renewable energy sources such as solar and wind power are integrated into the grid, their intermittent nature and decentralized nature pose challenges in accurately estimating their contribution to the system's inertia. WAMS can provide comprehensive data on power flows, voltages, and frequencies, allowing operators to estimate the hidden inertia associated with distributed renewable energy generation. By combining PMU measurements from various locations, operators can identify the dynamic behaviour and inertia characteristics introduced by renewable energy sources. This knowledge empowers them to devise appropriate control strategies, such as coordinating energy storage

systems or implementing advanced frequency control schemes, to ensure system stability and compensate for the reduced inertia from renewable sources.

They can estimate multi-inertia for multi-area systems, capturing the dynamics and interactions between different regions. Additionally, when combined with WAMS, PMUs can estimate hidden inertia associated with unknown renewable energy injection at the distribution level. This comprehensive understanding of inertia characteristics empowers operators to ensure the reliable and secure operation of power systems in the face of evolving energy landscapes.

9. Sub synchronous resonance (SSR)

The Sub Synchronous Oscillation (SSOs) or Sub synchronous resonance (SSR), may cause significant harm to generator sets and power systems; thus, online monitoring and accurate alarms for power systems are crucial for their safe and stable operation. Phasor measurement units WAMS can realize the dynamic real-time monitoring of power systems. Moreover, can Measured the state of interconnected power system with synchronized PMUS by WAM system.

11.4.2 Offline Applications

The offered solution shall include an offline software package for in-depth analysis and studies by NEPCO's engineers. The package shall be equipped with engineering analysis tools to leverage WAMS historical data stored internally or on an external data storage server for offline studies such as post-event analysis, model validation and calibration, and renewable resource integration.

The following functionalities shall be supported as a minimum:

- Import of historic data via CSV and COMTRADE file imports or database access, as well as importing simulated data from tools.
- Bad data detection and filtering.
- Statistical analysis to identify and locate hidden events in long term databases.
- Data manipulation options like resampling, interpolation, un-wrapping, normalizing, de-trending and differentiation.
- Time domain visualization using custom views, trending displays and charts.
- Chart annotation to annotate different type of analysis charts and results.
- Custom calculations functionality.
- Generation of customized and automatic reports of all analyses performed.
- Data export of all calculations, reports, charts and graphs generated to internal or external databases with support for data export in CSV and COMTRADE formats.

At the same time, the offline package shall support the following applications:

1. **Post-event analysis**

   High-resolution, time-stamped synchrophasor data provides an excellent insight into the reasons behind power system disturbances. It shall be possible to use synchrophasor data to study the sequence of events that led to a disturbance event, understand how the system responded, and be able to derive solutions to prevent similar events from happening in the future.

2. **Model validation and calibration**

   Synchrophasor data shall be utilized to validate and improve the accuracy of power system models, especially in regards to the dynamic performance of power system components. Synchrophasor data could be also used to validate the performance of generator models, system models, or dynamic load models.

3. **Renewable resource integration**

   The high granularity of synchrophasor data can provide better understanding on how renewable generation facilities could affect the grid and respond to changes in grid conditions. Synchrophasor data shall therefore be utilized in monitoring, modelling, managing and integrating intermittent renewable resources into the grid.

11.5 Future Expansions and Interoperability

As NEPCO is adopting a staged strategy in implementing WAMS applications, the offered solution shall be scalable to add new PDC and/or PMU devices with the ability to integrate additional application modules in the future. The Bidder shall ensure a seamless integration of future applications with the offered WAMS applications during the initial stage. The Bidder shall also provide details on the interface requirements and capabilities of the offered solution such as supported communication protocols and data export/import capabilities for each application module. Furthermore, the offered WAMS applications must ensure interoperability with WAMS applications and PDCs from other vendors. The Bidder shall provide a list of vendors that have successfully been interfaced with the offered solution in previous implementations.

11.6 SCADA/EMS Integration

The offered solution shall have the capability to integrate data generated by WAMS applications into the conventional SCADA/EMS system at NEPCO. It shall be possible to display specific WAMS applications data and be notified of alarm conditions once they occur via the SCADA/EMS displays at NCC. The integration shall be platform-independent and shall enable data access from different SCADA/EMS systems. The interface shall support standardized communication protocols such as IEC 60870-5-104, OPC UA, IEEE C37.118 and IEC 61850-90-5.

11.7 WAMS Common Information Model

The offered solution shall be capable of establishing a WAMS Common Information Model (CIM) as per IEC-61970 and IEC-61968 standard models enabling interoperability and data exchange among different proprietary systems operating at NCC control centres. The solution shall also support data exchange via the Component Interface Specification (CIS) defined under IEC-61970 for EMS systems.

11.8 WAMS Remote Access

To provide real-time remote access to WAMS data and applications from NEPCO NCC, it shall be possible to establish multiple secure remote sessions by designated NEPCO personnel. Remote sessions shall allow access to all real-time monitoring and analysis functionalities available to WAMS operators at NCC including advanced WAMS applications with no power to access or modify any of the configuration settings. It shall be possible to establish multiple remote sessions at the same time with assigned privilege access to WAMS applications and data. It is also important to ensure that the solution optimizes the design such that the remote access architecture is secure, easy to configure and not complex, i.e. it is not hard to maintain.

11.9 Software Requirements

WAMS applications system shall be based on standard firmware and software, which has already been implemented in other systems. Software configuration tools shall be available to adopt the system to the specific network layout, to do settings, to create displays, to define event and alarm text etc. Configuration software shall require no knowledge in programming languages or system source code.

All system software shall be implemented in a modular fashion to facilitate maintenance and modification of any of its parts. The system should allow new program modules to be added to implement future requirements without unduly affecting existing functions, and without requiring modification of any other module which is not affected by the new functional requirement.

The software shall be support network access control (Role Based Access Control) to grand the user the least privilege permission to complete his job or task.

Configuration software shall be provided to the user to configure, set up and modify the data acquisition, data processing and database system components to suit the requirements of specific application functions.

The system shall have an open architecture to ease data exchange between different applications and systems e.g. by providing interfaces and SQL access to its database. The Bidder/Contractor shall provide a summary of all Application Program Interfaces (API) and other interfaces, which can be implemented by NEPCO. The concept shall enable future extensions that exceed the functions defined in this specification.

The offered solution shall also ensure OS compatibility with all WAMS components including PMUs and PDCs.

Furthermore, the following details should be included for software requirement:

- The computer operating system shall be independent of the hardware configuration and application; it shall be a standard system and shall not be modified by the WAMS applications manufacturer.
- The WAMS applications software shall be selected from a library of standard modules, designed to operate under control of the operating system and interface efficiently with the database. It shall be written in a standard high-level language, suitable for the implementation of real-time function requirements. Details of the programming language proposed shall be advised.
- The latest release of software shall be supplied and tested at FAT. Consideration to updating the software package shall be given before expiration of warranty.
- A minimum program development shall be required for any special software, which has to be developed to meet the requirements of this specification. The Bidder/Contractor shall detail the function(s), which necessitate this work and provide an estimate of the work involved. Confirmation that the program will be supported for a minimum of 10 years is also required.
- It shall be the responsibility of the Bidder/Contractor to obtain any licenses required for the operation of the software. License registration for all software used in the project shall be registered under the name of NEPCO.
- The Bidder/Contractor shall indemnify NEPCO against all claims of infringement of any patent, registered design, copyright, trademark or trade name or other intellectual property right.
- The Bidder/Contractor shall detail maintenance philosophy and data recovery plan.
- All necessary cables, dongles, keys etc. shall be handed over to NEPCO.
- All USB ports shall be disabled after commissioning and shall be administered by the system administrator with passwords.

11.10 Security Requirements

The servers used for WAMS applications and workstations shall have cyber security features that enable the design of a system in compliance with industry standards as well as secure handling of the device, including user activity logging, authority handling, user management and system event logging over Syslog to enable a system-wide overview of system events. The servers shall also have per-port enable/disable capability of engineering access and communication protocols.

11.11 WAMS Workstations

WAMS workstations shall be made available at NCC control center. The following is the requirement.

11.11.1NCC WAMS Workstations

NCC shall have WAMS user interface workstations that are equipped with all the available WAMS applications including visualization, data analysis tools, and the advanced real-time and offline WAMS application modules that are specified in Section 11.4. NCC shall have at least one dedicated WAMS workstation. It shall be possible to implement the workstations using thin clients (web clients) and/or thick clients. It shall also be possible to integrate and access WAMS applications on the existing workstations.

At the same time, it shall have an engineering workstation for configuration, performance monitoring and maintenance. Through the engineering workstation, it shall be possible to do remote configuration, firmware upgrades and diagnostics of all PMUs and PDCs in the system. The workstation shall be used as well for configuring WAMS user interface, application parameters, reports, alarm thresholds, user accounts, etc.

Moreover, it shall be possible to install additional WAMS user interface and engineering workstations for concurrent users as needed without license limitation or software upgrades.

New WAMS workstations shall be of robust, durable construction, and shall be ergonomically designed to facilitate operation of the equipment mounted. The design, size, appearance and finish of the workstation have to be agreed to with NEPCO.

11.11.2Workstations

The bidder shall provide workstation devices for various purposes as follows:

- One workstations for WAMS data engineering, managing PDCs, and managing network devices equipped with the needed software applications for the relevant purpose.
- Two workstations for real time monitoring and viewing data from PDCs and WAMS
- Two workstations for off line historical data and viewing data from PDCs and WAMS.

The workstations shall have adequate resources (storage, processor, memory, NIC) with licenses for operating systems and any required client software applications for systems management like WAMS, PDCs, SSH clients for network devices, and others.For the data engineering workstation is shall be provided with data engineering software tools for PDC and WAMS in order to enable NEPCO personnel to manipulate power system collected data. The required facilities should be capable to derive, retrieve, manipulate, store and display data. It enables the worker to deal with the real time data as well as the historical data in terms of representing data, reporting, calculation and validation.
The required facilities shall provide the capability to query and manage database in order to encounter desired changes and regular requests. Furthermore, it shall be effectively achievable to create custom graphical elements, data points, calculations, display pages, lists and other objects that help visualized the power grid status and handle various issues by involved NEPCO team.
It should be possible to create custom calculations for various properties of power grids. Define and treat thresholds, alarms, events. Define various profiles for load, losses and others

11.12 Offline Analysis and Planning Tools

In order to support in-depth analysis and studying activities, WAMS offline software package described in Section 11.4.2 shall be available for minimum two users. The number of licenses and arrangements for accessing WAMS offline tools shall be as per scope and are subject to NEPCOs approval.

11.13 Service Conditions

The servers used for WAMS applications and workstations shall be capable of operating in ambient temperatures from -10° C to +50° C with a maximum ambient relative humidity of %77.

12. Training Facility

12.1 PMU and local/regional PDC

- The training shall be on-site training for hardware equipment and software training.
- The contractor shall provide all necessary training material.
- Each trainee shall receive individual copies of all technical manuals and all other documents used for training.
- The training courses and each course are identified in the below Table

No.	Training Course	Minimum Duration	Participation
1	PMU integration and configuration	5 Days	Persons responsible for Installation and commissioning
2	PDC integration and configuration and connection with PMU	3 Days	Persons responsible for Installation and commissioning
3	WAMS peripherals functionalities and administrations	2 Days	Persons responsible for Installation and commissioning and system administrators.
4	WAMS application real time and off line software	10 Days	Persons responsible for using and integrating the system

12.2 IT and WAMS Training

Training requirements include vendor training courses conducted locally in Jordan by a certified instructor, including official course materials. The vendor training designated for IT systems topics like network devices, storage, OS/virtualization administration, as well as topics for central PDC and WAMS systems administration.

The bidder shall train NEPCO's system technical staff to monitor and fully understand the installation and configuration process of NCC's hardware, operating system and WAMS Application.

The training shall cover comprehensive topics with remote access hands-on labs could be designated over several courses for all components of the provided NCC data network appliances and solutions. The training is designated to provide deep knowledge and experience that enable the NEPCO team to entirely employ, operate and manage the obtainable capabilities in the provided solutions. The labs can be access remotely and shall be similar to the planned environment.

The training shall be designated for OT environment Cybersecurity with best practices for configuring, operating, and troubleshooting the provided data network and security systems (data network devices, management software, etc.) and the supplied data center infrastructure systems (servers, virtualization, and storage,).

Training should cover detailed topics with hands-on labs regarding how to secure industrial protocols concerning the protocols incorporated in the scope of this project, as well as scenarios for securing the OT environment using the provided ICS firewalls and switches.

Conducted Training per topic, for each of the topics provide a comprehensive training plan indicating:

a. Course Title
b. Course Description
c. Duration of Course
d. Course Topics

13. Supply of Spare Parts

13.1 Spare parts requirements

The design life of PMUs shall be greater than 10 years, and the design of PDCs, WAMS applications and workstations shall be using industrial base equipment to extend their lifetime to the maximum. The Bidder/Contractor shall assure for long-term maintenance and availability of spares.

Moreover, a guarantee shall be provided for the availability of spares during the lifetime of PMUs, PDC. The Bidder/Contractor shall give one-year notice of his intention to cease manufacture of any components utilized in the contract works.

The Bidder/Contractor shall also provide a list of spares predicted as being required the first 5 years of operation for PMUs and for the application is for the first 2 years of operation and additionally over the design lifetime of the servers and additionally over the design lifetime of the PMUs. The Bidder/Contractor shall quote only with a fixed price escalation formula for these spares.

Should the equipment become obsolete, the Bidder/Contractor shall maintain compatibility of all software applications with existing and newly developed Operating Systems and hardware.

13.2 Spare parts Quantities

The Bidder/Contractor shall also provide a the listed item described in the below table as spares.

No	Item	Quantities	description
1	Ethernet switches for substations	Two	As required specifications
2	Central PDC	One	As required specifications
3	PMUs devices	10 circuits	40 Voltage inputs, 40 Current inputs, 20 Digital inputs and 20 digital outputs
4	GPS system	One	As required specifications

14. Performance Test:

When SAT is accepted, two weeks of normal operation without major fault should be granted. Major fault causes the system to stop functioning or performance is dramatically degraded. In this case, the two weeks' period is restarted again until there is no major fault happed within. When the two weeks is achieved, the first-year support will be started upon.

15. Maintenance and support (Support Levels)

Maintenance and support are considered a key role in evaluation criteria because keeping up the system running with high performance is the main goal of the contract. According to that, the bidder must send the available level of support for each hardware and software component. The bidder must provide a specific and precise description for each level and send the standard contracts signed between the bidder and clients.

Here, the Bidder must mention each level and yearly cost for each level in the BoQ for each year after the end of the support period in this contract (2) years.

The support does NOT cover the provided data networks part (ICS firewalls, switches, server(s) hardware, and workstations hardware) in the NCC data center or substation data networks.

NATIONAL ELECTRIC POWER COMPANY
TENDER NO. 31/2023 for Supply of
Phasor Measurement Units/Wide Area Monitoring System
PMUs/WAMS

SCHEDULE A/ MANUFACTURER TECHNICAL PARTICULARS

And DELIVERY DATES FOR PMU/WAMS System,

(Information to be submitted with tender)

ITEM	MANUFACTURER	TYPE	DELIVERY DATE CPT(QAIA)
PMUs			
PDCs (if used)			
Central PDC			
WAMS peripherals			
WAMS application			
Workstations			

NATIONAL ELECTRIC POWER COMPANY
TENDER NO. 31/2023 for Supply of
Phasor Measurement Units/Wide Area Monitoring System
PMUs/WAMS

SCHEDULE B/ PMUS Requirements

Phasor measurement units (PMU) Requirements

Sl. No.			REQUIRED	TENDERED
1.	**DESIGN & CONSTRUCTION**			
2.	**Mounting**			
3.	type			
4.	**Service conditions**			
5.	temperatures	deg C	-10 to +50	
6.	humidity	%	77	
7.	**Supply voltage**	V_{dc}	110 (+15%, -20%)	
8.	redundant power supply		yes	
9.	**Analog input module**			
10.	module channel capacity			
11.	number of channels per module			
12.	input current per channel	A		
13.	input voltage per channel	V	110 (+15%, -20%)	
14.	voltage range	V		
15.	tolerance	%		
16.	current range	A		
17.	tolerance	%		
18.	phase angle range	Deg.		
19.	nominal frequency	Hz	50	
20.	frequency range	Hz		
21.	**Digital input module**			
22.	module capacity			
23.	number of inputs per circuit		>=2	

24.	input type		Galvanically isolated	
25.	rated voltage	V_{dc}		
26.	Input voltage range	V		
27.	Input current at rated voltage			
28.	minimum mA	mA		
29.	maximum mA	mA		
30.	isolation type			
31.	optocoupler		yes	
32.	polarity reversal protection		yes	
33.	NO/NC contact selection		yes	
34.	contact bounce filter	µs		
35.	**Digital output module**			
36.	module capacity			
37.	number of outputs per circuit		>=2	
38.	output type		Isolated	
39.	rated load supply voltage	V_{dc}		
40.	output voltage range			
41.	minimum	V		
42.	maximum	V		
43.	maximum load current	mA		
44.	isolation type			
45.	**Communication ports**			
46.	Ethernet ports			
47.	number of ports		>=2	
48.	ports speed	Mbps	>=100	
49.	type		fibre	
50.	failover capability		yes	
51.	supported protocols			
52.	IEEE C37.118		yes	

53.	IEC 60870-5-104	yes	
54.	IEC 61850-90-5	yes	
55.	IEC 60870-5-101/103		
56.	Modbus		
57.	DNP		
58.	serial ports		
59.	number of ports		
60.	data rate Bd		
61.	interface type		
62.	USB ports		
63.	number of ports		
64.	**Time synchronization**		
65.	accuracy	±1μs	
66.	external clock synchronization	yes	
67.	time synchronization method		
68.	IRIG-B	yes	
69.	NTP	yes	
70.	PTP	yes	
71.	automatic resynchronization	yes	
72.	PMU data time-tagged using UTC	yes	
73.	**Self-supervision & alarms**		
74.	system power failure	yes	
75.	system controller failure	yes	
76.	communication failure	yes	
77.	loss of GPS synchronization	yes	
78.	loss of analog channels	yes	
79.	digital inputs alarms	yes	
80.	self-testing capabilities	yes	

81.	external signaling to SCMS and alarm panel	yes	
82.	alarms reporting in output data stream	yes	
83.	**Engineering Interface**		
84.	LEDs for status indication	yes	
85.	LCD display		
86.	visualization of measurements	yes	
87.	entry of parameters	yes	
88.	events and alarms	yes	
89.	Ethernet front port for engineering access	yes	
90.	**FUNCTIONAL REQUIREMENTS**		
91.	Stand-alone PMU functionality	yes	
92.	**Performance class**		
93.	P class	yes	
94.	**Measurements characteristics as per IEEE C37.118.1a-2014**	yes	
95.	accuracy		
96.	synchrophasors		
97.	frequency		
98.	ROCOF		
99.	resolution		
100.	synchrophasors		
101.	frequency		
102.	ROCOF		
103.	response time		
104.	synchrophasors sec		
105.	frequency sec		
106.	ROCOF sec		
107.	average latency sec		

108.	**Measurements and calculations**		
109.	voltage phase A magnitude and angle	yes	
110.	voltage phase B magnitude and angle	yes	
111.	voltage phase C magnitude and angle	yes	
112.	current phase A magnitude and angle	yes	
113.	current phase B magnitude and angle	yes	
114.	current phase C magnitude and angle	yes	
115.	voltage positive sequence magnitude and angle	yes	
116.	voltage negative sequence magnitude and angle	yes	
117.	voltage zero sequence magnitude and angle	yes	
118.	current positive sequence magnitude and angle	yes	
119.	current negative sequence magnitude and angle	yes	
120.	current zero sequence magnitude and angle	yes	
121.	frequency	yes	
122.	Rate Of Change Of Frequency (ROCOF)	yes	
123.	3-phase real power (MW)	yes	
124.	3-phase reactive power (MVAR)	yes	
125.	**Output data streams**		
126.	fully user configurable	yes	
127.	format compliant with IEEE C37.118	yes	
128.	reporting rates fps	10, 25, 50	
129.	minimum output data streams	2	
130.	support unicast and multicast data streams	yes	
131.	support redundant connections for each data stream	yes	
132.	supported data representation		

133.	floating point	yes	
134.	phasors in polar format	yes	
135.	phasors in rectangular format	yes	
136.	time source indicated in output stream	yes	
137.	**Control logic**		
138.	support for control programmable logic	yes	
139.	user configurable logic blocks	yes	
140.	configurable digital inputs and outputs	yes	
141.	**Software**		
142.	user-friendly tool	yes	
143.	configuration and engineering support	yes	
144.	online data monitoring	yes	
145.	data retrieval	yes	
146.	remote configuration and firmware upgrade	yes	
147.	**Cyber-security**		
148.	user activity logging	yes	
149.	user accounts management	yes	
150.	user access control	yes	
151.	system event logging	yes	
152.	communication ports enable/disable capability	yes	
153.	compliance to industry standards like IEC 62443 and IEC 62351	yes	
154.	**SUPPORTING DOCUMENTS**		
155.	All type test reports enclosed	yes	
156.	List of testing facilities enclosed	yes	
157.	QAP for components enclosed	yes	
158.	Relevant literature enclosed	yes	
159.	Relevant drawings enclosed	yes	

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SCHEDULE C/ PDC Requirements

Phasor data concentrator (PDC) Requirements

Sl. No.		REQUIRED	TENDERED
1.	**Manufacturer**		
2.	name		
3.	country of manufacturer		
4.	**Model**		
5.	**Platform**	software or hardware	
6.	**Applicable standards**		
7.	**Country of origin**		
8.	**Type test**	yes	
9.	date	dd-mm-yy	
10.	testing laboratory		
11.	name		
12.	country		
13.	**Date of first commercial operation of the unit**	dd-mm-yy	
14.	**MTBF**	hour	
15.	**MTTR**	hour	
16.	**Reference list attached**	yes/no	
17.	**PDC FUNCTIONAL REQUIREMENTS**		
18.	**General**		
19.	average latency	sec	
20.	**Input data streams**		
21.	fully user configurable	yes	

22.	ability to filter and select which data to stream		yes	
23.	ability to add input streams from other PDCs		yes	
24.	format compliant with IEEE C37.118		yes	
25.	reporting rates	fps	10, 25, 50	
26.	minimum input data streams			
27.	**Central PDCs**			
28.	support unicast and multicast data streams		yes	
29.	support redundant connections for each data stream		yes	
30.	supported data representation			
31.	floating point		yes	
32.	phasors in polar format		yes	
33.	phasors in rectangular format		yes	
34.	allows naming and labeling of data streams		yes	
35.	**Output data streams**			
36.	fully user configurable		yes	
37.	ability to filter and select which data to stream		yes	
38.	ability to include PDC calculations		yes	
39.	format compliant with IEEE C37.118		yes	
40.	reporting rates	fps	10, 25, 50	
41.	minimum output data streams			
42.	central PDCs			
43.	support unicast and multicast data streams		yes	
44.	support redundant connections for each data stream		yes	

45.	supported data representation		
46.	floating point	yes	
47.	phasors in polar format	yes	
48.	phasors in rectangular format	yes	
49.	allows naming and labeling of data streams	yes	
50.	buffer data in case of a communication link failure	yes	
51.	seamlessly restore data after communication link is restored	yes	
52.	**Mathematical calculations**		
53.	real and reactive power	yes	
54.	positive, negative and zero sequence components	yes	
55.	algebraic operations of phasors and analog values	yes	
56.	magnitude and angle scaling	yes	
57.	derivatives and rate of change	yes	
58.	rectangular and polar components of phasors	yes	
59.	**Control logic**		
60.	support for control programmable logic	yes	
61.	user configurable logic blocks	yes	
62.	ability to include control commands in data streams	yes	
63.	**Data archiving and retrieval**		
64.	archiving locations		
65.	internal database	yes	
66.	external database	yes	
67.	archiving methods		
68.	continuous	yes	
69.	event-driven	yes	

70.	archiving data rate	Msg per sec	multiple	
71.	supported archiving and retrieval formats			
72.	CSV		yes	
73.	COMTRADE		yes	
74.	**Configuration and performance monitoring**			
75.	user-friendly tool		yes	
76.	configuration and engineering support		yes	
77.	real-time performance monitoring			
78.	inputs and outputs status		yes	
79.	PMUs and PDCs data status and data quality		yes	
80.	archive status and utilization		yes	
81.	communication statistics and diagnostics (e.g. latency)		yes	
82.	diagnostic logs		yes	
83.	data retrieval		yes	
84.	remote configuration and firmware upgrade		yes	
85.	**central PDC requirements**			
86.	support platform-independent integration at the control center		yes	
87.	support integration of central PDC data into SCADA/EMS using:			
88.	IEC 60870-5-104		yes	
89.	IEEE C37.118		yes	
90.	IEC 61850-90-5		yes	
91.	support interface to other utilities via ICCP and C37.118		yes	
92.	**Communication ports**			
93.	Ethernet ports			
94.	number of ports		>=2	

95.	ports speed	Mbps	10/100/1000	
96.	type			
97.	failover capability		yes	
98.	supported protocols			
99.	IEEE C37.118		yes	
100.	IEC 60870-5-104		yes	
101.	IEC 61850-90-5		yes	
102.	IEC 60870-5-101/103			
103.	Modbus			
104.	DNP			
105.	serial ports			
106.	number of ports			
107.	data rate	Bd		
108.	interface type			
109.	USB ports			
110.	number of ports		4	
111.	**Self-supervision & alarm output contact**		yes	
112.	**Operating system**			
113.	Windows Server 2012 R2 or later, english-us, 64 bit		yes	
114.	**Engineering interface**			
115.	Ethernet front port for engineering access		yes	
116.	LEDs for status indication		yes	
117.	**Time synchronization**			
118.	IRIG-B		yes	
119.	NTP		yes	
120.	PTP		yes	
121.	**Display support**			
122.	DVI port		yes	

123.	HDMI port	yes	
124.	**All type test reports enclosed**	yes	
125.	**List of testing facilities enclosed**	yes	
126.	**QAP for components enclosed**	yes	
127.	**Relevant literature enclosed**	yes	
128.	**Relevant drawings enclosed**	yes	

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SCHEDULE D/ WAMS-PER Requirements

Wide Area Monitoring System Peripherals (WAMS-PER)

Sl. No.			REQUIRED	TENDERED
1.00	**COMMON FEATURES**			
1.01	Rated frequency	Hz	50	
1.02	Mounting		19" rack	
1.03	Tests			
1.03.1	immunity test		IEC-60255	
1.03.2	emissions test		IEC-60255	
1.03.3	insulation tests		IEC 60255-5	
1.03.4	environmental test		IEC-60068	
1.03.5	vibration test		IEC-60255-21	
1.04	Temperature range (min/max)	°C	-10 to 50	
1.05	Relative humidity	%	77	
2.00	**GPS (GLOBAL POSITIONING SYSTEM) RECEIVER**			
2.01	Manufacturer			
2.01.1	name			
2.01.2	country of manufacturing			
2.02	Type/Model			
2.03	Applicable standards			
2.04	Country of origin			
2.05	Type test		yes	

2.05.1	date	dd-mm-yy		
2.05.2	testing laboratory			
2.05.2.1	name			
2.05.2.2	country			
2.06	Date of first commercial operation of the unit	dd-mm-yy		
2.07	MTBF	hour		
2.08	MTTR	hour		
2.09	Reference list attached		yes/no	
2.10	Supply voltage			
2.10.1	substation installation	V_{dc}	110 (+15%, -20%)	
2.10.2	NCC installation	V_{ac}	230 ±10%	
2.10.3	redundant power supply		yes	
2.11	Dimensions of housing			
2.11.1	width	mm		
2.11.2	depth	mm		
2.11.3	height	mm		
2.11.4	mass	kg		
2.12	Cooling method			
2.12.1	natural convection		yes	
2.13	Receiver input	MH_z		
2.14	Timing accuracy to UTC time	µs of (UTC)	±1	
2.15	Aging: minimum operation period of the internal	years	15	
	oscillator in the specified accuracy limits			
2.16	Outputs			

2.16.1	unmodulated IRIG-B/PPS		yes	
2.16.2	modulated IRIG-B		yes	
2.16.3	DB-9 port		yes	
2.17	Time synchronization method			
2.17.1	IRIG-B		yes	
2.17.2	NTP		yes	
2.17.3	PTP		yes	
2.17.4	1PPS		yes	
2.18	Ethernet communication ports			
2.18.1	number of ports		>=4	
2.18.2	ports speed	Mbps	10/100/1000	
2.18.3	type		fibre	
2.18.4	PRP support		yes	
2.19	GNSS vulnerabilities mitigation			
2.19.1	solar flares		yes	
2.19.2	antenna failure		yes	
2.19.3	jamming		yes	
2.19.4	spoofing		yes	
2.19.5	software attacks		yes	
2.20	Self-supervision & alarms			
2.20.1	traceability to UTC		yes	
2.20.2	leap second changes		yes	
2.20.3	external signaling to SCMS and alarm panel		yes	

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SCHEDULE D/ WAMS) Applications Requirements

Wide Area Monitoring System (WAMS) Applications

Sl. No.	REQUIRED		TENDERED
1.00	**GENERAL**		
1.01	**Manufacturer**		
1.01.1	name		
1.01.2	country of manufacturer		
1.02	**Model**		
1.03	**Applicable standards**		
1.04	**Country of origin**		
1.05	**Type test certificates**	yes	
1.05.1	date	dd-mm-yy	
1.05.2	testing laboratory		
1.05.2.1	name		
1.05.2.2	country		
1.06	**Date of first commercial operation of the unit**	dd-mm-yy	
1.07	**MTBF**	hour	
1.08	**MTTR**	hour	
1.09	**Reference list attached**	yes/no	
2.00	**WAMS APPLICATIONS FUNCTIONAL REQUIREMENTS**		
2.01	**General**		
2.01.1	scalable solution allowing the addition of future applications	yes	
2.01.2	ability to develop user-defined functionalities and tools	yes	
2.01.3	no license limitation on additional concurrent users	yes	
2.02	**Visualization and Data Analysis Tools**		

2.02.1	single line overview with measurements and events	yes	
2.02.2	multilayered geographical map with measurements and events	yes	
2.02.3	trending displays	yes	
2.02.4	polar charts	yes	
2.02.5	events and alarms panel	yes	
2.02.6	events and alarms notifications	yes	
2.02.7	user-defined programmable logics and mathematical calculations	yes	
2.02.8	replay mode for incidents analysis	yes	
2.02.9	customized reports	yes	
2.02.10	system health status and diagnostics	yes	
2.02.11	system and applications logs	yes	
2.02.12	data export functionality to an internal or external database	yes	
2.02.13	user-friendly tool for configuration	yes	
2.03	**Real-time WAMS Applications**		
2.03.1	oscillation detection and monitoring		
2.03.1.1	detect and identify oscillation modes	yes	
2.03.1.2	characterize the damping behaviour of each mode	yes	
2.03.1.3	characterize the observability of each mode	yes	
2.03.1.4	provide early warning of oscillation modes	yes	
2.03.1.5	ability to operate during large disturbances	yes	
2.03.1.6	ability to operate during normal ambient conditions	yes	

2.03.1.7	user-defined warnings and alarms	yes	
2.03.1.8	access to historical data for analysis	yes	
2.03.1.9	ability to export results via CSV and COMTRADE file formats	yes	
2.03.1.10	maximum allowable data loss	%	
2.03.2	phase angle monitoring		
2.03.2.1	display of phase angle difference in real-time	yes	
2.03.2.2	display of max acceptable angle difference in real-time	yes	
2.03.2.3	display of the phase angle curve trend at selected locations	yes	
2.03.2.4	online warning and emergency alerting	yes	
2.03.3	voltage stability monitoring		
2.03.3.1	display of PV-Curve with indication of the actual loading point	yes	
2.03.3.2	calculation and display of actual power margin	yes	
2.03.3.3	display of voltage and current phasors at both ends of a line	yes	
2.03.3.4	display of natural loading point and nominal loading point	yes	
2.03.3.5	display of the actual active and reactive power flow	yes	
2.03.3.6	display of the direction of the active power transmitted	yes	
2.03.3.7	display of the equivalent impedance of the load area	yes	
2.03.3.8	data logging and trend display	yes	
2.03.3.9	online warning and emergency alerting	yes	
2.03.4	islanding detection, management, and restoration		
2.03.4.1	identify islands via colored areas on geographical map	yes	

2.03.4.2	display difference in frequencies and ROCOF	yes	
2.03.4.3	display max angle difference of all configured voltage phasors	yes	
2.03.4.4	data logging and trend display	yes	
2.03.4.5	online warning and emergency alerting	yes	
2.03.5	event detection and management		
2.03.5.1	display of anomalous power measurement waveforms	yes	
2.03.5.2	display of diagnosed events and recommended mitigation measures	yes	
2.03.5.3	data logging and trend display	yes	
2.03.5.4	online warning and emergency alerting	yes	
2.03.6	equipment problem detection		
2.03.6.1	identify equipment health issues and mis-operations	yes	
2.03.6.2	data logging and trend display	yes	
2.03.7	linear state estimators		
2.03.8	wide-area control and protection		
2.04	**Offline WAMS Applications**		
2.04.1	import historic and simulated PMU data	yes	
2.04.2	bad data detection and filtering	yes	
2.04.3	statistical analysis to identify and locate hidden events	yes	
2.04.4	data manipulation options	yes	
2.04.5	custom views, trending displays and charts	yes	
2.04.6	chart annotation	yes	
2.04.7	custom calculations	yes	
2.04.8	customized reports of analyses results	yes	

2.04.9	data export functionality to an internal or external database		yes	
2.04.10	supported applications			
2.04.10.1	post-event analysis		yes	
2.04.10.2	model validation and calibration		yes	
2.04.10.3	renewable resource integration		yes	
2.05	**Data archiving and retrieval**			
2.05.1	archiving locations			
2.05.1.1	internal database		yes	
2.05.1.2	external database		yes	
2.05.2	archiving methods			
2.05.2.1	continuous		yes	
2.05.2.2	event-driven		yes	
2.05.3	archiving data rate	Msg per sec	multiple	
2.05.4	supported archiving and retrieval formats			
2.05.4.1	CSV		yes	
2.05.4.2	COMTRADE		yes	
2.06	**SCADA/EMS/EMS/EMS/EMS integration**			
2.06.1	support platform-independent integration at the control centre		yes	
2.06.2	support integration of Super PDC data into SCADA/EMS/EMS/EMS/EMS		yes	
2.07	**Common Information Model (CIM)**			
2.07.1	WAMS Common Information Model (CIM) per IEC-61970/IEC-61968		yes	
2.07.2	CIM data exchange per IEC-61970/IEC-61968		yes	
3.00	**WAMS WORKSTATIONS DESIGN & CONSTRUCTION**			
3.01	**Service conditions**			
3.01.1	temperatures	deg C	-10 to +50	
3.01.2	humidity	%	77	

3.02	**WAMS user interface and engineering workstations**			
3.02.1	type		Thin client PC	
3.02.2	supply voltage	V_{ac}	230 ±10%	
3.02.2.1	redundant power supply		yes	
3.02.3	CPU			
3.02.3.1	processor		Multi Core	
3.02.3.2	speed	GHz	>=3.5	
3.02.4	memory	GB	>=16	
302.5	internal storage			
3.02.5.1	type		SSD	
3.02.5.2	size	GB	>=128	
3.02.6	Ethernet ports			
3.02.6.1	number of ports		>=2	
3.02.6.2	ports speed	Mbps	10/100/1000	
3.02.6.3	failover capability		yes	
3.02.7	time synchronization			
3.02.7.1	NTP		yes	
3.02.7.2	PTP		yes	
3.02.8	display support			
3.02.8.1	DVI port		yes	
3.02.8.2	HDMI port		yes	
3.02.9	software			
3.02.9.1	Windows 10 IoT Enterprise or later, English-us, 64 bit		yes	
3.02.9.2	support for VDI environment and RDS		yes	
3.02.10	workstations setup			
3.02.10.1	LCD monitors - user interface workstations		2 x 32"	

3.02.10.2	LCD monitors - engineering workstations	1 x 32"	
3.02.10.3	mouse	yes	
3.02.10.4	keyboard	yes	
3.02.10.5	speakers	yes	
3.02.10.6	printer	yes	
4.00	supporting documents		

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SCHEDULE F/ QUANTITIES AND PRICES

The prices entered below for the item, whether or the item is fully described, shall include everything necessary to provide the equipment complete and in working order in accordance with the provisions of the contract.

The following schedule shall be filled in completely and without omissions by the tenderers, and their manner and break-down may not be changed; however, extra sheets may supplement this schedule, should that be necessary.

No.	Item	Quantity	Unit cost	Total cost
1	PMU			
2	PDC in substations or storage			
3	Central PDC			
4	GPS System			
5	Ethernet Switches			
6	Routers			
7	Main ICS Firewalls			
8	Antimalware			
9	Real-time applications			
10	Off line application			
11	WAMS Workstations			
Total				

Total Price for the Equipment CPT (QAIA) .....

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SCHEDULE G/ QUANTITIES AND PRICES for training

The prices entered below for the item, whether or the item is fully described, shall include everything necessary to provide the equipment complete and in working order in accordance with the provisions of the contract.

The following schedule shall be filled in completely and without omissions by the tenderers and their manner and breakdown may not be changed; however, extra sheets may supplement this schedule, should that be necessary.

No.	Training Course	Minimum Duration	price
1	PMU integration and configuration		
2	PDC integration and configuration and connection with PMU		
3	WAMS peripherals functionalities and administrations		
4	Master WAMS real time and off line software		
5	IT and WAMS Training		

Total Price for the training .....

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SCHEDULE H/ QUANTITIES AND PRICES for Spare parts

The prices entered below for the item, whether or the item is fully described, shall include everything necessary to provide the equipment complete and in working order in accordance with the provisions of the contract.

The following schedule shall be filled in completely and without omissions by the tenderers, and their manner and break-down may not be changed; however, extra sheets may supplement this schedule, should that be necessary.

No	Item	Quantities	price
1	Ethernet switches for substations	Two	
2	Central PDC	One	
3	PMUs devices	10 circuits	
4	GPS system	One	

Total Price for the Equipment CPT (QAIA) .....

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SCHEDULE I/ Total PRICES for all project

The prices entered below for the item, whether or the item is fully described, shall include everything necessary to provide the equipment complete and in working order in accordance with the provisions of the contract.

The following schedule shall be filled in completely and without omissions by the tenderers, and their manner and break-down may not be changed; however, extra sheets may supplement this schedule, should that be necessary.

No	Item	Total price (currency)
1	Whole PMUS/WAMS system project including all the required items (Supply materials, FAT, commissioning, training, etc.…..)	

IMPORTANT NOTICE

a. Failure to fill this table and provide the relevant testimonials and end user certificates for the mentioned projects will result in rejection of the tender.

b. General reference list will not be considered for eligibility purpose.

c. NEPCO will contact with end-users, so clear address should be indicated otherwise the offer will be rejected.