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Technical Thesis

The Role of EMS in the Hellenic Power Grid

By

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A B S T R A C T

This Thesis deals with the Hellenic Energy Control System. The main issues described are the technical specifications, the appliance in wind power technology and the upgrade of the system.

The first two chapters describes the most important parts and functions of the system.

At the second part the appliance of such a system in a wind farm is described and there is the first objective of the Thesis, the creation of a **Load Management Algorithm**. This algorithm has also been converted into C programming language.

Finally at the last chapter there are some proposals and a **method** to use in order to **upgrade** the current system, and this is the second objective of the Thesis.

CHAPTER 1

TECHNICAL SPECIFICATIONS FOR THE HELLENIC ENERGY CONTROL SYSTEM

INTRODUCTION

OBJECT OF SPECIFICATION

The Public Power Corporation of Greece (thereafter designated by PPC) has considered the installation of a system which would use the most advanced computing elements, hardware and software subsystems to provide monitoring, supervisory control, and energy management of the Hellenic generation and transmission electrical power system. This control system will be hereafter designated as “Energy Control System” or “ECS”.

This hierarchical control system consists of :

a) Master Control Stations with redundant computers for the National Control Centre and for the two Regional Control Centres the “Northern” and “Southern” with corresponding responsibility for the geographical Northern and Southern areas of the interconnected system.

The National Control Centre and the Southern Regional Control Centre are installed in Ag. Stefanos area (Athens) in the same premises while the Northern Regional Control Centre are installed in the Ptolemaida area.

b) Remote Terminal Units are located at the various power plants and transmission system substations.
c) Transducers, and generator unit controllers.
d) Power Line Carrier communications with redundant paths and transmission equipment.
e) Miscellaneous equipment.

The System collects, transmits, computes, displays, alarms and logs all the data necessary for the real-time supervision, control and operation of the Hellenic Power Generation and Transmission System. It also controls the operation of the circuit breakers of the 400 KV and 150 KV stations. In addition the system performs all the functions specified herein.

The System provides improvements in the Power System operation regards power system security, quality of service, and economy. Economic considerations, however, become secondary when abnormal operating conditions occur in the Power System, while security related functions all the time aim at reducing the probability that system-wide emergencies ever develop. The System provides the Power System dispatchers with the real-time information and the short-term predictions required to make better and faster judgements concerning the Power System taking into consideration that the decision making role always lies with the dispatcher.

DESCRIPTION OF THE HELLENIC POWER SYSTEM

Generation

PPC is the sole authority in Greece responsible for the generation transmission, and distribution of electric energy to the ultimate consumer.

PPC's main objectives are :

a) To meet in an economical way the country's constantly increasing requirements in electric energy.

b) To utilize in full all domestic sources of energy.

c) To supply electric power to all consumers in towns and villages of the country.

PPC has conducted extensive studies in order to meet the increased power demand of the next decade, taking into consideration the progressive independence from imported oil. The major part of the generation is produced from local sources i.e. lignite and water.

There are two power plant complexes. The one in the North, in an area of about 40 km radius from Ptolemaida with an installed lignite and hydro capacity 55% of the total system capacity, and the other in the west in an area of 70 KM radius from Kremaste with hydro capacity 16,3% of the total. The distance of these two areas is about 360 KM from Athens.

78% of the energy is produced in the Ptolemaida power complexes, while 32% of the energy is consumed in the Athens area and vicinity.

Transmission

The transmission of electric energy to the entire mainland and to a few adjacent islands is carried out by means of 400 KV, 150 KV and 66 KV lines.

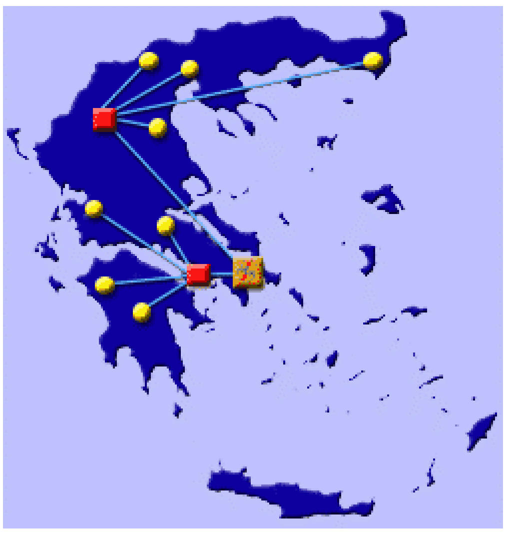
The 66 KV voltage level is used only for the interconnection of the Kerkyra island with the mainland.

Some of the 150 KV lines (radial) in the Athens area have distribution task. The distribution network is radially operated. The medium voltage is 20 KV and the low voltage 380/220 V. In some regions still exist 15 KV lines which are gradually converted to 20 KV and in Athens area 22 KV.

Due to the necessity of installing the lignite and hydro units in the vicinity of the lignite fields and the respective rivers which, however, are distant from the load centres, the transmission becomes even more significant with increased reliability requirements.

The 400 KV network is the bulk power transmission network and consists of the following axes transporting energy from the generating centres to major metropolitan areas :

- The Ptolemaida region – Athens axis ;
- The Ptolemaida rergion – Thessaloniki axis ;
- The Acheloos region – Athens axis ; and
- The Lavrion – Athens axis.



While the 400 KV network are being expanding to be used as the bulk power transmission system the 150 KV network will also continue expanding bringing about amore well meshed network to be used as a secondary energy transmission system.

Most 400 KV substations have 3 bus – bars arrangements and many 150 KV oens 2 bus – bars schemes with bus ties. Step – down 400/150 KV substations have 3 or 4 pairs of autotransformers with on–load tap changers and one shunt reactor per pair connected on the 30 KV side on either of the autotransformers and in many substations, capacitor banks are connected to the 20 KV side of 150 KV distribution substations.

Considering the bulk energy transfers and the generating incremental costs, it is worthwhile to play on the dispatch of real power generation and on the action of tap changers, shunt reactors and static condensers to minimize network losses and cost.

The scarcity of water resources imposes a careful unit scheduling. Lignite plants supply the base load with hydro plants picking-up peak load.

Power and Energy Forecasts

- Seasonal variations in the consumption are small.
- The weekly consumption is characterized by four types of days : Saturday, Sunday, Monday and Weekdays.

A brief general information for the Hellenic System concerning the present situation is given below :

1. Medium and low voltage consumers : 5.187.436
2. Number of Industrial customers directly connected to the high voltage transmission system : 25 + 3 Lignite Mines
3. Net production of electrical energy of the interconnected system.

   Lignite .... 16155 GWH (65,5%)

Hydro	2791	GWH	(11,3%)
Oil	4969	GWH	(20,1%)
Intertie Balance	739	GWH	(3,1%)
Total	24654	GWH	(100%)

4. Number and installed capacity of HV S/S's of the interconnected system :

400 / 150 KV	12	7890	MVA
150/20 , 150/22 , 150/15 KV	103	7242	MVA
150/66 , 66/15 , 66/20 KV	3	208	MVA
Step-up S/S's MV/150 KV	17	5250	MVA
Total	135	20590	MVA

5. Number of C8's of the interconnected system :

400 KV	94
150 KV	580
66 KV	6
30, 22, 20, 15 KV	1206
Total	1886

6. Transmission line lengths of the interconnected system :

400 KV double circuit line	1115	km
400 KV single " "	168	km
150 KV double " "	2175	km
150 KV single " "	4156	km
66 KV " " "	39	km
Total length	7653	km

7. Distribution line lengths :

HV (150 KV cables) 113 km; (66 KV cables) 4.7 km;

MV 61.227 km

LV 69.156 km

Total 130.501 km

POWER SYSTEM MANAGEMENT

Voltage Control Equipment

Voltage control of the transmission network is achieved by :

- Capacitor banks.
- Shunt reactors.
- The hydraulic and thermal generators.
- One 50 MVAR shunt reactor per pair connected on the 30 KV side on either of the 400/150 KV autotransformers.
- On – load tap changers of the 400/150 KV autotransformers and the 150 KV / MV transformers.

Tie Lines

The Hellenic transmission system is interconnected with :

- The Yugoslavian system through one 150 KV line (PTOLEMAIDA – BITOLA) and one 400 KV line (THESSALONIKI – NEGOTINO).
- The Bulgarian system through a 400 KV line (THESSALONIKI – BLAGOEVGRAD).
- The Albanian system through a 150 KV line (IGOUMENITSA – BISTRICA) and one 400 KV line (KARDIA – ELBASAN).

The AC simultaneous interconnection of the power systems of Greece, Yugoslavia, and Bulgaria is not technically possible because Greece and Yugoslavia are in synchronous parallel operation with the interconnected power systems of the West – European countries (U.C.P.T.E.), while Bulgaria is in synchronous parallel operation with the interconnected power systems of the member countries of the Council for Mutual Economic Assistance (C.M.E.A.).

The tie lines which are connecting Greece to the East and West European grids are more sensitive to outages of large portions of generation; since Greece is at the extreme end of the European grids, therefore, local load shedding is anticipated.

SYSTEM DESIGN PHILOSOPHY

National Control Centre

The responsibilities of the National Control Centre related to power generation and transmission management consist of operation planning, and weekly and daily scheduling.

The system design philosophy associates certain functions with each of these responsibilities.

The Operation Planning includes :

- Long Range Analysis related to annual planning and management of system load, unit scheduling, unit maintenance, interchanges, power flows, water reservoirs and fuel supplies.
- Evaluation of the effectiveness of short range management and scheduling functions as performed by the on-line power application programs.
- Collection of Statistical and historical data related to system planning requirements to be used by mathematical system models.

The Weekly and Daily Scheduling includes :

- Formulating and implementing of operating procedures and policies for normal and emergency conditions within the PPC system and with other countries.
- Management of international interconnections by implementing the Interchange Scheduling and Interchange Evaluation functions.
- Automatic Generation Control (closed loop control) together with AC Performance Monitor, Economic Dispatch and Reserve Monitor.
- System Energy Monitor.

- Security Analysis function as :
  - Network Configuration
  - State Estimation
  - Real – time Load Flow
  - Security Analysis with contingency selection
- Unit Commitment
- Bus – Load Forecast
- Dispatcher's Load Flow
- Production cost
- Optimal Power Flow

The NCC operator is able to initiate the following actions for remote control :

- Load Shedding / Restoration
- 400 KV Breaker's Control
- Tap change control of the 400/150 KV autotransformers
- Shunt reactor control

When initiating any of the above control actions, they are carried out automatically by the RCC supervisory control software.

At any time the RCC control operator is able to initiate the same types of control actions as the NCC control operator, providing that the NCC and the RCC are not acting to control the same substation simultaneous and only after the NCC operator has changed the tag of the substation from National to Regional Control.

The NCC is responsible for the operation of its computers, software, MMI, and communications subsystems as well as for the operators training by implementing a Dispatcher Training Simulator Program.

Regional Control Centres

The Regional Control Centres, an integral part of the ECS, are primarily operating centres. The system design philosophy associates the following functions with the regional management responsibilities :

- Implementing control for the respective regions for the 150 KV and 400 KV transmission system either automatically or in response to a communicated directive from the NCC.
- Executing the Automatic Generation Control (AGC), Economic Dispatch (ED), Regulation Margin Dispatch (RMD), Penalty Factors, Reserve Monitoring (RM), and AGC Performance Monitoring together with the Interchange Scheduling (IS) function only in the NRCC if at the NCC the execution of the AGC is interrupted.
- Directly controlling the regional transmission network 150 KV and 66 KV based on policies communicated from the NCC, either automatically or by dispatching personnel to the substation.
- Collecting and processing data through RTU's and communication system for use at the NCC and maintaining files for historical purposes.
- Operating the RCC's software, computers, MMI, and communication subsystems.
- Autonomous emergency decisions in case of serious incidents are expected to be made in accordance with general directives pre-issued by the NCC.

GENERAL SYSTEM REQUIREMENTS

System Configuration

The hardware configuration features of the ECS are :

A. One or two level, redundant, multiprocessing, at least 32-bit CPU system at the NCC and a single level, redundant, multiprocessing at least 32-bit CPU system at each RCC ;

B. man / machine interface at the NCC and at each RCC ;

C. communication processors ;

D. microwave and power line carrier communications with redundant paths and transmission equipment ;

E. computerized remote terminal equipment, transducers, generator governor controllers.

The ECS includes almost total redundancy throughout the system and significant growth capacity for expansion.

The Computer Subsystem

The Computer Subsystem consists of a full redundant system capable of operating in a multiprocessing mode, with parity protected memories associated bulk memories and peripherals. Two identical computer subsystems are provided per control center.

One or two level, redundant, multiprocessing, at least 32-bit CPU system at the NCC and a single level redundant, multiprocessing at least 32-bit CPU system at each RCC are provided.

The main CPUs of the two (2) Regional Master Stations (the four (4) main CPUs) are identical.

Both of the above configurations meet or exceed the loading requirements, response times and expandability specified in the Sections that follow.

The NCC computer system performs the applications and process related functions, the man-machine functions and the communication functions. The computer system of the NCC has the capability to be interfaced with the Management Information System (MIS) and to a PRIME computer model 550.

The RCC computer system utilizes a one level, fully redundant configuration supporting among other, Man / Machine Interface functions, communications with RTUs and the NCC, as well as, for only the NRCC Automatic Generation Control (AGC), Economic Dispatch (ED) with Regulating Margin Dispatch (RMD), Penalty factors, Reserve Monitoring (RM) and AGC Performance Monitoring together with the interchange scheduling (IS) function if at the NCC the execution of the AGC is interrupted.

All key systems components are duplicated or otherwise backed up to achieve high reliability for critical system functions. No single failure cause loss of a critical function.

The peripherals in the system at each level are individually accessed by either computer through dual ported design and through specific peripheral switches except in the case that dedicated CPU peripherals are used. Peripheral switches are CPU A or CPU B and permit both manual and CPU – directed modes except for line printers. In the CPU – directed mode, either of the CPUs is capable of controlling the switch position. Regardless of operational mode, same level CPUs receive an indication of the actual switch position. The failure of a single CPU does not prevent the proper functioning of any switched data path or device connected to the other CPUs, including the ability to switch the device(s) away from the failed CPU. If the dual port or dual access type devices are used, similar recommends for non – interference in the case of CPU failure are met.

All real – time I/O devices are switchable between computers. Redundant power supplies (in case of redundant devices installed in same cabins transient suppression devices are provided. Failed devices are automatically replaced by back – up devices if such devices are available. A back-up data base including non-recoverable data (manually entered data, tags, calculated values, etc) should not be lost upon failover. Methods of CPU – to – CPU data transfers are acceptable so long as the operational reliability and data transfer requirements (to complete one data transfer of all the real-time data within ten (10) seconds) are maintained.

Normally one of the computers, designated as “primary” performs the real-time functions while the other computer, designated as “secondary” are maintained in a backup, not standby, position to take over the primary functions in case the primary computer fails. The designation of primary or “secondary” computer is determined automatically by the system when a computer is brought up. In case of failure an automatic “fail-over” procedure is implemented.

There are four modes of operation of these two computers :

- Backup mode
- Pseudo – primary mode
- Training mode
- Stand alone mode

The communication between the NCC and the Southern RCC is direct because of the physical proximity of the NCC and RCC computers.

Communication with the Northern Regional Control Center are via three microwave communication channels and are low speed 4800 BPS mixed microwave link and PLC link as back-up.

The NCC computer subsystem includes :

A. Application level computers with terminals (in case of two levels configuration.

B. Process level computers with terminals (in case of two levels configuration or application and process computers with terminals (in case of one level configuration).

C. Controllers and Peripheral Switches.

D. CPU – CPU Link

E. Peripherals :

- Line printers
- Discs
- Magnetic tapes
- Loggers
- Programmers terminals

F. Multiple MMI equip. controllers for :

- Consoles
- Strip chart drivers
- Mapboard drivers
- Time and Frequency subsystem

G. Multiple communication processors for :

- Remote Consoles / Loggers
- Data Links

Each RCC computer subsystem includes :

A. Application and Process computers with terminals.

B. Controllers and Peripheral Switches

C. CPU – CPU ling

D. Peripherals :

- Line printer
- Discs
- Magnetic tapes
- Loggers
- Programmers terminals

E. Multiple MMI equip. controllers for :

- Consoles
- Strip chart Drivers
- Mapboard drivers
- Time & Frequency subsystem

F. Multiple communication processors for :

- Remote Consoles / Loggers

- RTU's
- Data Links

<u>Man / Machine Interface (MMI) Subsystem</u>

<u>Man / Machine Interface (MMI) at the NCC</u>

The MMI hardware at the NCC provides a completely redundant real – time control with interactive and full – graphics capabilities.

The man / machine interface in the Control Room of the National Control Center consists of :

A. Consoles with CRT's trackball, alphanumeric keyboard, functional keyboard and telephone communications switchboard ;

B. A dynamic mimic wall board containing the map of the 400 KV and 150 KV power system driven by the computers ;

C. Strip Chart Recorders driven by the computers ;

D. Loggers ;

E. Video color printer ;

F. Telephone communications recording system.

<u>Man / Machine Interface (MMI) at the RCC's</u>

The MMI hardware in each Regional Control Center is identical except in quantities of units, and provides a completely redundant real – time control with interactive and full – graphics capabilities.

The man / machine hardware of each RCC consists of :

A. Consoles with CRT's, trackball, alphanumeric keyboard, functional keyboard and telephone communications switchboard ;

B. A dynamic mimic wall board containing the map of the 400 KV and 150 KV area power system driven by the computers ;

C. Strip chart Recorders driven by the computers ;

D. Loggers ;

E. Video color printer ;

F. Telephone communications recording system required only for the NRCC, since the SRCC is served by the same recording system as the NCC.

Communications Subsystem

The communications subsystem includes all hardware necessary for data communication between the system RTUs and the Northern and Southern Regional Control Centres except microwave equipment.

It also includes all hardware necessary to perform the data and voice communication between the RCCs and NCC in Aghios Stefanos (Athens) area. Existing Microwave and PLC equipment together with existing line traps, coupling capacitors, tuning elements and HF cables are extensively used for the data transmission.

Overall System Design

The communications subsystem for the Hellenic Energy Control System requires the greatest reliability that is practical to ensure the flow of data from all parts of the remote stations to the Regional Control Centres (Northern and Southern) and to the National Control Centre. Power line is used in the majority to form the communication network between the Regional Control Centres and the remote stations and microwave channels serve as a communication path in the portion of the Hellenic Energy Control System that requires high density and / or high – speed data transmission. Each important portion of the data flow that is required at the Regional Control Centres from the Remote Terminal Units, is provided with a back – up route for reaching its destination should the prime signal path be interrupted during a fault condition.

Southern RCC to NCC Computer to Computer Data Links

The data communications between the Southern RCC and the NCC, both situated at Ag. Stefanos NCC & SRCC building, are realized via 3 direct computer to computer data links at speed of 19200 bps. Two of the links in operation and one hot standby.

Northern RCC to NCC Computer to Computer Data links

The data communications between the Northern RCC in Ptolemaida area and the NCC in Athens area is realized via 3 microwave data communication links at 9600 bps (two operating and one hot standby) all in parallel a fallback Microwave and PLC data commnication link at a lower transmission 4800 bps. The latter will be transformed into a fully 9600 bps microwave link in the near future.

Remote Equipment

Equipment is installed at each of the remote facilities to interface with the power system. The equipment consists of remote terminal units, transducers and generator governor controllers.

Power Supply Equipment

General

The Ag.Stefanos National Control Centre (NCC) and Southern Regional Control Centre (SRCC), and the Ptolemaida Northern Regional Control Centre (NRCC) buildings are supplied each one from two independent substations by separate cables as well as from a standby quick starting diesel generator set as a back–up. The primary source is 380/220 V, 3–phase, 4–wire, 50 Hz.

Ag. Stefanos Building (NCC + SRRCC)

a. Uninterruptible Power Supply (UPS) unit consisting of a fully redundant parallel operating system with all the necessary controls, static switch, manual bypass switch, e.t.c.

necessary for the reliable operation of the system under all operating conditions.

b. DC power supply consisting of redundant battery chargers batteries and DC switchgear and panels.

c. Critical Buses.

System Activity Level Definition

For the purpose of specifying the system performance under different system activity levels, the terms “steady state”, “high activity state” and “peak state”, are defined below.

Steady State

The system is said to be in a steady state when all of the following are true for a five minutes period :

a. The system is scanning and processing status, analog, and accumulator data from all the RTUs in the ultimate system configuration with the following assumptions :

A 2% status change is considered.

A 100% status dump is considered.

For 2 sec analogs 100% exceed dead band check limits.

For 4 sec and 10 sec analogs 50% exceed dead band check limits.

100% accumulators processed once in a 5 min period.

100% MWH calculated every 20 sec.

b. All CRTs are updated (refreshing existing displays with the latest real – time data) every 5 seconds.

c. A data entry / min / console, an alphanumeric display / min / console, a schematic display / min / console are entered and called up respectively by the operator at each local and remote console and terminal.

d. Mapboard is updated as appropriate.

e. A total of five (5) supervisory control requests per 5 min. period are processed.

f. Console process (buttons) for 2 displays / min / console, 1 data entry / min / console, 5 supervisory requests and alarms acknowledged as indicated in g and h below.

g. A 2% change in Alarms is processed.

h. A 25% of processed alarms is acknowledged.

i. Message process logged for data entry, supervisory request and alarms acknowledged.

j. A Report creation and control for :

Total reports to be printed 10

Total pages to be printed 100

Average numbers of displays / page : 2

K. A Trend Recorder output average rate every 6 seconds.

l A Video Trend average rate every 6 seconds.

m. A Disturbance Data Collection every 10 seconds.

Scanning rates and points :

2 sec ,	100 analog points
4 sec ,	100 analog points, 200 digital
10 sec ,	100 analog points

Length of total disturbance : 0,5 + 1 + 1 = 2,5 minutes

(predisturbance, disturbance and postdisturbance)

n. A Periodic Collection / calculation :

Integration rate : 10 secs

Number of integrations : 1500

Calculated value rate : 20 secs

Number of calculations : 1100

o. A Historical Data Storage collection is performed every 5 min period. Number of values 100.

p. At least fifteen (15) seconds have elapsed since the system was in the high – activity state.

q. AGC is operating normally.

r. All on–line programs are operating normally with the following number of runs completed within 5 minutes period.

PROGRAM	PERIOD (sec)	NUMBER OF RUNS WITHIN 5 MIN. PERIOD
- AUTOMATIC GENERATION CONTROL (AGC)	4	75
- AGC PERFORMANCE MONITOR (APM)		1
- ECONOMIC DISPATCH (ED) WITH REGULATING MARGIN DISPATCH (RMD)		1
- TARGET PASS GENERATION DISPATCH (TPGD)		1
- INTERCHANGE SCHEDULING (IS)	300	1
- RESERVE MONITOR (RM)	60	5
- SYSTEM ENERGY MONITOR (SEM) (20 secs period for digital integration calculation)	20	15
- SYSTEM ENERGY MONITOR (SEM) hourly for reports		1
- SHORT TERM LOAD FORECAST (STLF)		1
- INTERCHANGE EVALUATION (IEV)-ECONB FOR A TWELVE (12) HOUR TRANSACTION		1
- REAL – TIME PRODUCTION COST (PC)	300	1
- OPTIMAL POWER FLOW (OPF)		1
- REAL – TIME SYSTEM STATUS PROCESSOR (SSP)		1
- STATE ESTIMATION (SE) WITH UNOBSERVABLE NETWORK CALCULATION		1
- REAL – TIME LOAD – FLOW (RTLF)		1
- NETWORK LOSS FACTORS (NLF)		1

- CONTINGENCY ANALYSIS (CA) REAL – TIME (60 single and 60 multiple for screening, 30 single and 30 multiple for analysis) - STUDY MODE (60 single and 60 multiple for screening, 30 single and 30 multiple for analysis).		1 1

High – Activity State

The system is said to be in the high – activity state when both the following are true :

a. The system has been in the steady state and is performing all the steady state functions

b. Three (3) alarms per second are being processed by the System and acknowledged by the operators.

Peak State

The system is said to be in the peak state when both of the following are true :

a. The system has been in the steady state and is performing all the steady state functions.

b. A burst of five hundred (500) status and / or alarms occur within a fifteen (15) second period.

Scan Time Requirements

Data is retrieved from RTU's at the following rates :

- AGC analogs every two (2) seconds
- State Estimation analogs every four (4) seconds
- Other analogs every ten (10) seconds
- Fuel consumption, Water discharge,

Water head analogs every nine hundred (900) seconds

- Circuit Breakers (CB) Status every four (4) seconds or if the RTU supports it, the status can be retrieved by exception. In the last case then there is a status dump to verify that the status at the RTU matches the system's data base.
- Isolators (IL) and Earthing.
  Switchers Status and Alarms every ten (10) seconds
- Transformer taps indications every ten (10) seconds
- AGC control every four (4) seconds
- Status Dump every six hundred (600) seconds

Steady State Utilization

When the system is in the steady state, the system utilization is as follows :

a. The average utilization of each CPU over any five (5) minute period is fifty percent (50%) or less.

b. Over any five (5) minute period, each bulk memory subsystem is not be busy with data transfers for more than fifty percent (50%) of the time. The average utilization factor is fifty percent (50%) or less over any five (5) minute period.

High – Activity State Utilization

When the system is in the high – activity state, the system utilization is as follows :

a. The average utilization of each CPU over any five (5) minute period is sixty percent (60%) or less.

b. Over any five (5) minute period, each bulk memory subsystem is not busy with the data transfers for more than sixty percent (60%) of the time. The average utilization factor is sixty percent (60%) or less over any five (5) minute period.

Peak State Utilization

When the system is in the peak state, no alarms are lost and normal functions continue to be supported. System response times may be degraded, however, the elapsed time of the executions of the ON – LINE power system application programs doe snot increase noticeably.

Display Response Time for LOCAL CONSOLES

The display response time is defined as the elapsed time from the instant the display request is made by the System Operator (by pressing a pushbutton or selecting a poke point) to the instant the requested display is completely shown on the CRT screen. Since identical display requests will produce different display response times, depending on the availability of the computer system resources at the instant of the requests, the display response time requirements are defined in terms of mean and worst case time for 10 requests per display Type.

With the system in the steady state or high – activity state and with system operators at all local consoles simultaneously requesting different new displays, the display response times of the different types of displays conform to the time given in the following two tables plus 0,5 sec for every simultaneous selection.

Under peak activity state conditions, display response times of the various types of displays shall be less than 1,5 times the display response times given in Table 2.

Allowable Display Response Times

Table 1

Steady State Display Access Times

Display Type	Average Response Time	Maximum Response Time
SCADA displays including one-line	1.5 second	2.0 seconds

diagrams		
EMS displays including unit and system summaries	1.5 second	2.0 seconds
Static Background of Window I/O display types	1.5 second	2.0 seconds
Dynamic Portions of Window I/O displays	2.0 seconds	3.0 seconds
Static background of Applications displays requiring calculations of formatted from disc	1.5 second	2.0 seconds
Dynamic Portion of Applications displays requiring calculations or formatted from disc	2.0 seconds	3.0 seconds
Dynamic Summary displays formatted from Queues	2.0 seconds	3.0 seconds
Tabulars	2.0 seconds	3.0 seconds

Table 2

High Activity Display Access Times

Display Type	Average Response Time	Maximum Response Time
SCADA displays including one-line diagrams	2,0 seconds	2.5 seconds
EMS displays including unit and system summaries	2.0 seconds	2.5 seconds
Static Background of Window I/O display types	2.0 seconds	2.5 seconds
Dynamic Portions of Window I/O displays	2.5 seconds	3.5 seconds
Static Background of Application displays requiring calculations	2.0 seconds	2.5 seconds

or formatted from disc		
Dynamic Portions of Application displays requiring calculations or formatted from disc	2.5 seconds	3.5 seconds
Dynamic Summary displays formatted from Queues	2.5 seconds	3.5 seconds
Tabulars	2.5 seconds	3.5 seconds

Alarm Response Time

With the system in the steady state or high – activity state, an alarm (analog and / or status) detected at an RTU is reported by audible and visual alarms at the Master Station within the scan time period for the particular data point in alarm, plus one second.

If the appropriate alarm summary display and / or station display containing the point alarm are already being shown on the CRT's, then the appropriate entry on the display is also updated within the above specified time period.

With the system in the peak activity state, all alarms are secured against loss and then processed at the maximum practical rate to result in completion of processing of the entire alarm burst within a maximum of 100 seconds.

System Operator Request Completion Time

With the system in the steady state or the high – activity state, the system completes the response to a System Operator request within the time period indicated here below :

- Point selection on a CRT : CRT display confirmation of point selection within one (1) second.
- Alarm Acknowledgement : stop flashing, within one (1) second, message print – out started within 10–15 secs following acknowledgement.

- Data entry verify : data verified, unacceptable entries identified within two (2) seconds during the high activity state.
- Hardcopy request : start printing within five (5) secs.
- Control request : the system confirms the control action selected within one (1) second.
- Control execute : message sent to the RTU within five (5) secs during the high activity state.
- Control point tagged : tag shown on CRT, message print out started within five (5) seconds.
- Status / analog point deactivation : processing on the point stopped deactivation indication shown on the appropriate displays within one (1) second.
- Alarm inhibit : alarm checking on the point stopped, inhibit indication shown on the appropriate displays, within one (1) second.

Under peak activity conditions, the response to a System Operator request does not add more than 2,25 seconds for each of the above requests.

For System Operator requests which are normally expected to exceed one (1) second, such as those requiring lengthy calculations, the system posts a requested – accepted message within one (1) second followed by an action completed message (or some other appropriate indication) when the given function is completed.

SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA)

Data Acquisition

The data acquisition function is responsible for handling all the communications with the RTUs. It supports the message exchange sequences for all scan modes and generate the necessary commands to retrieve supervisory data and status information. It also perform all required error checking to ensure the validity of the received data and / or proper completion of scans.

Transmission and error checking of control functions are handled by the data acquisition system. Command functions have priority over the normal scan and are initiated as soon as the current activity in the communication channel is completed. Scanning shall then resume from the point of interruption.

The data acquisition function contains provisions for scheduling the data scans as well as the following :

- Automatic diagnostic checks of all Data Acquisition CPUs and peripherals including auxiliary and / or back up devices when used to ensure proper operation of these devices.
- Automatic diagnostic checks of all communication line controllers, including auxiliary and / or back up devices when used to ensure proper operation of these devices.
- Initialization scan to be performed at system reload or initialization such as following a power failure. This scan consists of a complete system data and status update.
  Following this initialization scan the normal scanning sequence shall resume.
- Provide an updated data base accessible to application programs via standardized access routines. Each data point in the data base has indications of whether the data was successfully retrieved (updated) on the last scan, the point was deactivated, or the value was manually updated by the dispatcher.
- Initiate and process the verification of all supervisory control functions.

- Allow a dispatcher to define an RTU as being on or off the scanning sequence.
- Allow a dispatcher to tag a point and (if applicable) thus prevent supervisory control actions from being sent to the remote point.
- Allow a dispatcher to inhibit a point from CRT and audible alarming and logging.
- Allow a dispatcher to remove a point from processing.

Data Scanning

The data acquisition function provides for initiation of an RTU scanning sequence based on any or several criteria :

- Periodic scans at one or more of at least eight pre-defined rates.
- Initialization scan upon starting up the System or an RTU.
- Program triggered scans.

For the case of periodic scans, scan – frequency assignment and scan – priority assignment there are data base parameters, changeable through the interactive data base editor.

The scan priority scheme dictates that initiation of data scanning for a priority scan group interrupts the scan of data in a lower priority scan group at the next instant the RTU is available to receive a scan request message. Upon completion of the high priority scan, the scanning of the data group having the next highest priority is resumed.

The linkages between scans and triggering mechanisms are data base parameters, changeable through the use of the interactive data base editing function.

Communication Error Checking

Each reported data message is immediately checked for certain basic error conditions, including incorrect response, message length error, communication failure detected by hardware checking or message security codes, etc. Detected errors are filtered before alarms are generated to preclude excessive alarms due to noisy channel conditions. Attempts shall be made to recover from the error conditions by repeating the particular data scan for a predetermined number of times (configurable). If no more errors are detected in at least one of the retries, then the earlier error shall be considered as a recoverable error. Otherwise, it shall be considered as a non-recoverable error. Statistics (number of detected errors for pre-defined time period) shall be kept on recoverable errors. The detection of a non-recoverable error or the occurence of a high number of recoverable errors (e.g., 30%; configurable parameter) shall be considered as channel – failure and shall result in the suspension of scanning for the particular RTU, along with an alarm. The dispatcher then will be able to restart the scanning.

Scan Suspension

The capability is provided to interactively (via CRT displays) suspend the scanning of any given RTU upon dispatch request. This action is not the same as the deactivate action for individual data points, in which a particular point is scanned but it is not further processed. The quality – coding indications for every data point within a CRT for which the scan is suspended reflects the fact that the data will not be further updated.

Supervisory Control

The functional requirements for supervisory control are described in this section. Four types of supervisory control are provided :

- Digital Control
- Autotransformer Tap Control
- Generator Raise / Lower Control
- Setpoint Control

The system supports partitioned operation whereby supervisory control types may be permitted from certain console positions and denied from others.

The system provides the capability for imposing software interlocking conditions between selected sets of points. This holds for the disconnecting and grounding switches of the 400 KV substations.

Digital Control

All digital control commands to the RTU's are treated with priority. These control commands are used to control circuit breakers, isolators, earthing switches, reactor breakers, and other types of substation devices with 2 state control.

The supervisory control function involved in the control of two state devices have the following safe capabilities :

a. All dispatcher – requested control selections are checked for proper conditions for control of the device (no other control actions in progress at this RTU, this point not selected for control at some other console, control of the said point allowed from this console, no control inhibit, tag effective for this point, interlocking in effect for this point).

b. The system acknowledges the above and indicate to the dispatcher that this selection has been verified (select – before – operate).

c. The dispatcher either cancels his selection or executes the control command within a predetermined time interval (configurable). In the latter case, the system performs the select – before – operate sequence from master to RTU and after completion acknowledges the execution of his command.

d. It is possible to choose different time – out durations for each controllable device at the time of data base generation. The time – out period are variable from one second to ten minutes. After expiration of the time – out, the system initiates an alarm message.

e. After detection of change of state in the RTU the status is analyzed to ascertain that the proper control action took place.

f. The system updates the data base.

g. If communication errors occur during the select – before – operate sequence, the system retries the operation up to three times in succession (programmable number). If it is impossible to obtain proper communication or if the RTU does not respond with the proper message, the dispatcher is alarmed with an appropriate message different from the time out message.

Generator Raise / Lower Control

For purposes of controlling generator units, a special form of digital control is required, as follows :

- Control commands between master and RTU are direct operated rather than select – before – operate.
- Control commands from master to RTU include the desired raise or lower pulse length to be output by the RTU. It is possible to vary raise and lower pulse lengths between 0 and 1.5 secs in 0.1 second increments.
- No limitation is placed on multiple raise / lower control operations occurring simultaneously.

Setpoint Control

The System supports setpoint control, whereby control commands are issued to the RTU to establish desired analog value handoffs.

Setpoint commands employ a select – before – operate message sequence between master and RTU or an equivalent safe procedure.

DATA PROCESSING

Real – Time Analog Data Processing

After requested analog data from an RTU have been received without error, they are subjected to limit checking.

Every analog value is checked against predefined and changeable high and low limits which are to be individually specified for each point.

These limits are :

High / Low Reasonability Limits : The maximum and the minimum readings of the transducers – Beyond these limits readings are to be considered unreasonable and are not used to update the system data base.

High and Low Emergency Limits : A reading beyond one of these limits is an indication of an emergency state of the power system or power device.

High and Low Operational Limits : A reading beyond these limits is an indication of a deviation from the normal operational guidelines.

Detection of a limit violation results in appropriate audible alarm, timely display update, and logging of the alarm. A return – to – normal indication and logging is also provided when this alarm condition returns to normal. Each of the above three sets of alarm limits is treated separately ; e.g., an analog data which has returned to normal from a reasonability limit alarm may still be in the emergency – limit alarm state and / or in the operational limit alarm state. A deadband which is equal to a percentage of the difference between the high limit and the low limit, is applied to the magnitude of each of the limits to derive the return – to normal level.

Selected analog data (for any 200 analog data) is checked for rate – of – change of limit values.

For each selected analog value, the total net change in value over the scan interval is computed as an engineering unit value change per second. The computed change is compared against a predefined rate – of – change limit value, also expressed as an engineering unit value per second. An alarm is generated if the limit is exceeded.

The system provides for A/D drift detection. Two data integrity points are provided for analog – to – digital (A/D) converters in each RTU. These precision reference points are sampled and utilized to determine the extent of errors of the A/D converters. If the A/D values retained for these integrity points drift outside predefined high / low limits, a system alarm is generated to indicate the problem and the analog points in that RTU are set to telemetry error.

The basic conversion of analog values to engineering units is made by assuming a linear transducer characteristic of the general form $Y=mX+b$, where m and b are the coefficients defining the scaling and offset of the analog point.

To eliminate surge and spikes caused by electromagnetic interference analog data is filtered by use of filtering techniques.

Real – Time Status Data Processing

Status data is processed for every scan period when such data are received. The newly received status is compared against the current status in the data base to determine if changes have taken place (unless report – by – exception is used). Change of status of power system devices not initiated by the operator result in appropriate audible alarming display update, and logging of the changes. Operator – initiated change of status does not result in an alarm but the change shall be logged on the event logger. The system is designed to ensure that no change of status is lost due to communication errors or other causes except in the case of total failure of the system.

The alarm / indication data is processed to determine the current status and to report any change of status. Each alarm / indication point is monitored though a dry contact which may be a form “a” or “b” contact ; the correspondence to open or closed states is a data base assignable parameter. Both the alarm conditions and return – to – normal conditions are reported. The correspondence between a “normal” condition and the dry contact status (open or closed) is a data base parameter changeable through the CRT – interactive data base modification procedure.

Motor – operated switches are monitored by separate contacts to indicate fully closed and fully open positions. The system correctly interprets and show switch position as being fully closed, fully open or in transit. Some motor – operated switches are equipped for automatic operation (changing position without operator initiation).

Breakers equipped with reclosers are monitored with status – with – memory (change detection) inputs. The breaker status and the change detection status are correctly interpreted to indicate and record the following breaker operations which may occur within one scan time period :

- From close to trip
- From close to trip to close
- From close to trip to close to trip
- From trip to close
- From trip to close to trip

Return – to – normal conditions is alarmed and logged.

<u>Real – Time Accumulator Data Processing</u>

Selected points have watt – hour meters which report data to the pulse accumulators at the RTU. Accumulator readings are retrieved and processed every 15 minutes (configurable). The following functions are performed on pulse accumulator input data :

- Data conversion to engineering units.

- Data storage in the data base and in historical files.

If one or more accumulator readings are missing due to RTU failure, master station failure at the time of scheduled accumulator scan, or communication error, the scaled accumulations for the associated time periods are flagged as being bad in the data base and historical files. At least M retries, where M is a changeable parameter, are attempted before an accumulator reading is declared “bad”. Appropriate alarming is provided for these conditions :

The accumulator reading is flagged as “bad” for any hour in which the RTU has experienced a power failure.

If the operator manually enters hourly accumulators data, the values he enters are saved in the system data base and otherwise processed just like “good” accumulator data received from the RTU.

Calculated Data

A calculated point is a point whose value or state is a function of the value (s) or states of one or more points (component points). The component points may be points being monitored at several RTU’s, local analog inputs, data or states received from the data link (s), and / or dispatcher – entered data or other calculated points. The value or state of a calculated point are calculated by using a predefined algorithm.

The value of a calculated point is calculated and updated due to one of the following predefined triggering events :

- Periodically at defined multiples of one second
- At specified status changes
- Operator demand
- Specified time of day

A calculated point is stored in the data base for display, logging, and other functions, in such a way that whether it is calculated or a monitored point, appears identical to the accessing programs.

Like the monitored analog and status data, each calculated value is checked against preset high and low limits or against defined normal and abnormal states, and limit alarm messages and return – to – normal messages are provided when appropriate.

The algorithm is pre – stored and available from a CRT display such that a calculated point can be defined by simply specifying the component data points and referencing the particular algorithm desired by the dispatcher.

DEVICE TAGGING

The System provides the capability of tagging a device with any one of the following tag definitions :

The required tags are :

Out of Scan	May be associated with an point type-data base value or state – Is not to be updated with new telemetered data.
Tap Changer Control Inhibited	May only be associated with a data base point that has been defined as having control – No control commands are allowed to be sent to the RTU for this point.
Open/Close Control Inhibited	May only be accociated with a data base point that has been defined as having control – No open / close commands are allowed to be sent to the RTU for this point.
Information Only	May be associated with any point type – Allows a comment to be associated with a point but does not

	restrict the interface with point in any way.
Alarm Inhibit	May be associated with any point type – Does not allow alarm processing for this point.

Each tag type causes a unique single character tag indicator to be displayed on dispatcher screens that show the value or state of the associated point. This indicator optionally defines variable positions as part of the screen definition. The tag types have a unique priority and the highest priority tag present on a point determine which tag indicator to display.

Each tag contains at least the following information for log and tabular display :

- Point name
- Station name
- Date
- Time
- Minimum or 15 characters of dispatcher entered comments.

The System is capable of supporting tagging operations (add and delete) from any display in the system that the associated point appears on. All tag operations are logged on the Alarm and Event Log upon occurence.

LOAD SHEDDING / RESTORATION (LS / R)

The Load shedding / restoration (LS/R) function operates on a computer – directed semi – automatic mode by the dispatcher. This function provides the dispatcher with a convenient and rapid method of opening and closing groups of circuit breakers without the need to individually select and operate each breaker separately.

The data base used by the program contains a pre – stored list of circuit breakers which can be operated by the LS/R program. This list could be modified by the programmer / engineer using appropriate editing. Only those devices contained in this list are affected by the LS/R function.

Using the appropriate LS/R displays, showing groups of breakers with total group megawatts (associated with controllable breakers), the dispatcher is able to open or close all circuit breakers in a group which are in a controllable state. The dispatcher has displayed the total amount of group MW which can be shed if the controllable breakers are operated. This amount of power will be retained on the display for his reference in restoring service to the group loads which have been shed.

The LS/R program supports at least 20 control groups with each group containing at least 40 breakers.

CHAPTER 2

TERMINAL UNITS OF THE PPC

GENERAL DESCRIPTION

The terminal units of the ECS are installed in selected points in the power grid and have been selected by the PPC.

The aim of these units is to gather information from the network, transmit these information to the control centres, receive information from them, decode them and transmit them to the relevant substation.

All the information from and to the substation are gathered in the first cabin of the ECS, in the TDB (Transducer Distribution Board).

In this unit the transducers, interposing relays, which are used for remote control are installed.

The next unit is the RTU (Remote Terminal Unit), which is the most important unit of the terminal station. It consists of the central processing unit, the communication cards and the analog and digital input and output cards.

The PLC unit gathers the telecommunications equipment of the substation. The major unit is the PLC (Power Line Carrier), which is connected to the high voltage line through the proper devices.

There are specific occasions where two substations are connected with underground cables specially installed by the PPC. In this occasion the PPC uses specialised equipment for high voltage protection installed to the PCTB (Pilot Cable Terminating Board).

The interconnection between ECS and PPC takes place through telephone lines installed at the LFD (Low Frequency Distribution) cabin.

TDB UNIT

The TDB unit is the interposing level for the interconnection of the PPC substation with the ECS. In this unit all the information from and to the PPC are gathered.

The analog values are interpreted through transducers which convert the analog input signal (usually alternating current or alternating voltage) in such a format that can be easily read by the RTU. (DC of 0 – 10 mA or $\pm$ 10 mA). The transducers have a pulse output which is measured by the equivalent measuring card of the RTU.

The transmission of remote control commands from the RTU to the PPC takes place through interposing relays installed at the front side of the TDB and to the telecommunication network so that they can be easily connected to the field.

At last there are communication lines for the connection of the digital input signals and the analog output signals. In these occasions knife disconnected terminals are used so that every signalled can be isolated, without the need of disconnecting the cables.

It is interesting to mention that the ECS uses 227 TDB cabins. In those cabins there are 502 active/idle power transducers, 76 energy transducers, 865 current transducers and 120 voltage transducers.

REMOTE TERMINAL UNIT (RTU)

The RTU is the major unit of the system. It consists from a computer specially designed for industrial environment and from a number of peripheral cards specially designed for the communication and execution of specific commands.

The RTU collects all the information (analog or digital), elaborates them and transforms them to a proper format in order to send them to the control centre. At the same time it receives signals from the control centre, examines their correctness and does their execution.

The RTU equipment is placed into a 2.2 x 0.8 x 0.8 metres cabin. In this cabin there can be one to four racks. The card which consist the RTU are :

- MP41, MP49, ME45

This is the Central Processing Unit (CPU). The microprocessor is the 6809 in 2 MHz.

It has communication lines with peripheral devices such as PCs or printers.

The total memory capacity is 4 pages of 64 Kbytes RAM and 128 Kbytes EEPROM.

There is parity control for every information which is stored and read from the RAM unit. At the same time the RAM has a battery for the information protection in case of a power outage.

- AL07

Digital input card. It has 32 input channels with galvanic isolation organised in 4 bytes. The nominal voltage is 48V.

- RL 02

Digital output card with relays. It has 16 output channels and the ability to control the circuit and the working status of the relays.

- RL 00

Digital output card with relays. It has 8 double channels and it is specially designed to control devices that demand a separate contact for ON and OFF condition. This card prevents the system to give a simultaneous ON and OFF condition in a device.

- AA 12

Digital input card. It has 32 input channels. Every input is galvanic isolated through a ‘flying capacitor’ circuit.

- AA 05

This card converts the analog signal to digital. The parity is 12 bits + sign + overflow index. The precision is 0.1 % and it has selfcontrol ability.

- RA 00

Analog output card with 4 channels. It has galvanic isolation and the ability to drive a load of up to 3 Kohm. The precision is 1 % and the output current can be 0 – 5 mA, 4 – 20 mA, +- 5 mA, +- 10 mA, +- 2.5 mA.

- AC 00

Pulse measurement card. It has 4 channels with galvanic isolation and measurement ability of 7 or 8 bits. It is used for energy measurement.

- CS 41

It is the 'watchdog' card of the system. It also has a temperature control circuit and it gives an alarm signal at 50 or 60 C. Furthermore it has a control circuit for the remote control voltage.

- CS 00, CS 01, CS 05

They are used to transfer the RTU bus to the extension racks.

- AI 01, AI 02, AI 03

Feeding cards. They accept –48 VDC and they produce all the necessary system feeding voltages. (+5V, +-12V and +-15V).

The communication between RTU and control centre takes place through a MODEM device. The main features of this device are :

- Serial Full Duplex transmission.
- FSK configuration.
- Communication speeds of 50, 100, 200, 300, 600 and 1200 Bauds.
- 55 receipt and transmission programmable channels.
- Set- up of the receipt and transmission parameters with the aid of a portable computer.
- Estimation of the signal to sound ratio.

The communication speeds of the ECS are 300, 600 and 1200 BPS.

PLC CABIN

The dimensions of the cabin are: 2.2 x 0.7 x 0.65 metres. It contains the PLC (Power Line Carrier), the terminating set and the EMM 312 unit. The above constitute the telecommunication equipment of the system.

PLC (Power Line Carrier)

The PLC is used to transmit information through the high voltage lines. The operation is bi-directional and the SSB (Single Side Band) method is used to transmit the 300 – 3700 Hz frequencies to the 40 – 500 KHz area. The transmission takes place through 3 sequential configurations. The acoustic information is primarily configured at 24 KHz and filtered in order to live only the bottom side zone. After that there is a second configuration at 600 KHz and after the filter only the upper side zone exists. The final configuration takes place through a digital frequency synthesizer.

After the filter only the bottom side zone exists and the signal enters the power amplifier and through the exit filter and proper device to the high voltage line.

At the receiver stage we have the opposite procedure in order to decode the signal and reverse the frequencies at their basic values of 300 – 3700 Hz.

In order to counterbalance the losses from the transmission line we use an AGC (Automatic Gain Control) circuit. A predefined frequency is being sent from the emitter to the receiver. Any change at the amplitude of the frequency is identified by the receiver and through the proper circuit the receiving gain is regulated in order to stabilise the frequency's amplitude.

Through this procedure the receiving signal remains stable despite the fluctuations of the losses of the transmission line.

The maximum power of the amplifier is 60 W/ 75 Ohms and its last stage comprises of MOSFETs of A – B class polarity which has as a result very low distortions. It also has the ability to drive lines of 50, 75 and 150 Ohms.

TERMINATING SET

Through this unit it is feasible to transmit voice and data simultaneously at the same communication channel. The acoustic spectre 300 – 3700 Hz is separated in two zones with the appropriate filters. The first zone 300 – 2000 Hz is used to transmit voice while the second zone 2280 – 3400 Hz is used to transmit data.

The terminating set has the connection ability with a simple telephone line (2 – wire) or a telephone centre (4 – wire and E + M signalling and control line frequency at 2220 Hz).

At the same time there is the ability of telephone connection of two directly connected substations through a 'staff telephone'.

EMM 312 UNIT

(Modular Multifunction Equipment)

The EMM 312 unit is designed to provide a series of functions for the integration of the telecommunication equipment.

Its basic capabilities are :

- The distribution and concentration of the communication channels (Diffusor – concentrator). In that way it is to transmit a channel in different directions and to gather channels from different directions in one channel.
- The transposition and filtering of a communication channel.
- In order to achieve these functions the device uses the digital signal processing method. In that way the signal converts from analog to digital. The processing takes place through software (ADSP 2101 microprocessor) and after that is converted to analog in order to reach the output in this format.

LFD (LOW FREQUENCY DISTRIBUTION) UNIT

This unit (0.8 x 0.4 x 0.2 metres) is the interposing telecommunication stage between the ECS and the PPC.

It consists of telephone lines with the ability to temporarily interrupt the connection in order to perform other interconnections to the network and perform the necessary controls and checks.

PCTB (PILOT CABLE TERMINATING BOARD) UNIT

It is necessary to protect the telecommunication equipment from high voltages, especially when this equipment is installed in PPC's substations, where the telecommunication cables may be in parallel with High Voltage lines.

For this reason there protection devices installed at the PCTB cabin. These devices consist of isolation transformer, varistors, arrestors and suppressor diodes.

FEED AND AUTONOMY SUBSTATION UNIT

In order to provide current for the devices the appropriate voltage is –48VDC. The feeding device is a switching mode one with the ability to provide current of 15 to 135A. At the same time it charges the Ni – Cd batteries which are used to feed the substation's equipment in case of interruption at the main voltage of 220VAC. The autonomy can last at least for two hours. The capacity of the batteries is from 18 to 240Ah accordingly to the consumption level of each substation.

CHAPTER 3

SUPERVISORY CONTROL IN WIND FARMS

INTRODUCTION

It is a fact that wind energy has done a remarkable progress the last years and it is now feasible to integrate it and produce power. Under specific circumstances the cost of wind energy is now comparable with the cost of power from fossil fuels. It also has the advantage of being an environmental friendly energy, something which is very important for our society.

The Public Power Corporation of Greece (PPC) has started an extensive program of exploiting the wind energy especially in the islands of the Aegean sea with the financial help of the EU.

A wind energy unit is usually much smaller than the usual diesel units of a small power station.

The most common sizes of wind turbines are 55, 75, and 100 KW. We are not sure that this is the ultimate size for financial exploitation since the last years there is a tendency to install wind turbines of 200 and 300 KW. Of course there have been installed much bigger wind turbines but usually for experimental reasons. Usually an area with an amount of 10 wind turbines and more is called Wind Farm (WF), which is monitored from a control system. The WF is connected to the local electricity grid at the middle voltage of 15 KV or 20 KV of the island through transformers of 220 KV. The rest of the electricity grid is using diesel engines.

In every WF there are several meteorological instruments installed. The measurements from these instruments are transferred, together with other information for the function of the WF, to the Energy Control System from where the engineers can adjust the function of the WF. At the same time other information regarding the oil units of the station are gathered.

At this point it will be useful to see a brief analysis of the Energy Control System of 50 wind turbines in 7 WFs in islands of the Aegean Sea. (Limnos, Hios, Karpathos, Samothraki, Ikaria, Samos)

FUNCTIONS

The Energy Control System of the Wind Turbines (WT) consists of three different levels of electronic equipment. These three levels correspond to the (WF), to the autonomous generation station (AGS) and to the directorate of renewable energy of the PPC (DRE) in Athens.

The functions in each level are:

1. Wind Farm (WF) level

Collection of the necessary data for the function of the WTs, the meteorological data and the data from the (AGS).

Supervision of the lines and equipment for the telecommunications of the units.

Keeping of records with the data from the WTs and the diesel electricity production couples (EPC) of the (AGS).

Reception of remote control commands from the computer of the (AGS) and transmission to the WTs.

Entry from the user through keyboard/monitor interface of the commands for the remote control of the WTs. This will be necessary only in the case that the WTs cannot be controlled from the AGS.

Man – Machine Interface (MMI) through keyboard/monitor and printer for the following functions :

- The decision if the remote control of the WTs will take place from the control room of the WF or from the control room of the AGS and the transmission of the proper commands to the WTs.

- The ability for the user to have real time and recorded data for both the WF and AGS.
- The generation of computer programs for the control of the WTs or the computer of the AGS.

2. Autonomous Generation Station (AGS) level.

Collection of the functional data of the EPC of the AGS and transmission of them to the computer of the WF.

Collection of data for the function of the WTs from the computer of the AGS.

Communication with independent Energy Control System of the AGS for the exchange of functional data for the diesel EPC.

Communication with the computer of the DRE in Athens for the transfer of real – time data of both the WF and AGS. At the same time there is transfer of data regarding the function of the WTs and the EPC.

Execution of the load management program, issue of commands for the remote control of the WTs and transfer of these commands to the computer of the WF.

MMI through keyboard/monitor and printer for :

- Entry of remote control commands for the WTs and transfer of them to the computer of the WF through keyboard and monitor.
- Presentation of real time and recorded data for the function of both the WF and AGS.
- Modification of input data for the load management program.
- Generation of computer programs for the remote control of the units.

3. Athens Directorate of Renewable Energy (DRE).

Automated telephone calls through scanning to the various AGSs in order to transfer the data from the function of the WF and the AGS.

Reception of the above data and creation of records.

Execution of programs for the analysis of the functional data.
Man – Machine Interface (MMI) through keyboard/monitor for the above.

EQUIPMENT – COMMUNICATIONS

The electronic equipment of each WT relies upon a microprocessor and gives the ability of serial communication with the Information Collector (IC) of the WF.

Apart from the IC in the WF who communicates with the WTs and receives the data from the meteorological stations, there is also a personal computer for the handling of this data.

There is also similar equipment i.e IC and PC in the AGS for the collection of data from the diesel generators and the supervision and management of the system.

The communication with the DRE in Athens, where there is also a PC for every AGS, is achieved through the public telecommunication network through an automated choice.

The equipment of the WF and the AGS consists of specific circuits for the protection from thunders and power outages.

ELABORATION OF SIGNALS AND MEASUREMENTS

The data gathered in every scan are :

For every WT :

KW – produced active power
KVAR – produced idle power
WSP – speed of wind/wing/generator
T - temperature of gearing box, small generator, large generator
Operation time for the small generator
Operation time for the large generator
Total amount of energy produced by the WT.

Operational condition (fuselage position, brakes, connection to the grid etc.).

Operation errors

For the WF :

V – network voltage

WSP – wind speed

WDIR – wind direction

TEM – external temperature

PRESS – pressure

For every generator :

KW – produced active power

KVAR – produced idle power

Generator switch position

Operational limits

For the AGS :

V – 20 KV bus voltage

F – grid frequency

KW – total active production

KVAR – total idle production

KW – total production capability

KW - WF line active power

KVAR – WF line idle power

WF line switch position

WTs remote control commands (Direction, START, STOP)

KW – departure active power

KVAR – departure idle power

KW – internal consumption active power

KVAR – internal consumption idle power

The above information is collected from the Information Collectors and are transferred to both the WF computer and AGS computer. Every

10 minutes a ‘historical record’ is created with the maximum, minimum and middle values of the most important measurements.

The above data is necessary for the statistical analysis which takes place at the AGS or DRE computer in Athens.

The system operator has the ability through his monitor to access the WTs operational data and handle the diagnostic messages of every different category.

There is a database at the AGS computer that handles all the WTs measurements and signals. This database works in real time mode so the system operator has the ability to remote control the WTs function and the normal connection of the WF to the power grid of the island.

LOAD MANAGEMENT

The load management program exists at the AGS computer with the aim to produce the ultimate amount of energy taking into consideration the safety rules for the diesel EPC and the whole system in general. The criteria which are taken into consideration are :

- WTs start availability
- Wind speed and duration (stability)
- System reserve and ability to start or interrupt a number of WTs
- WT participation in the production of electricity
- WT circular function

The operator supervises the system and decides upon the following :

- Diesel unit start/stop
- Load redistribution in the available diesel units
- Capacitors connection/disconnection

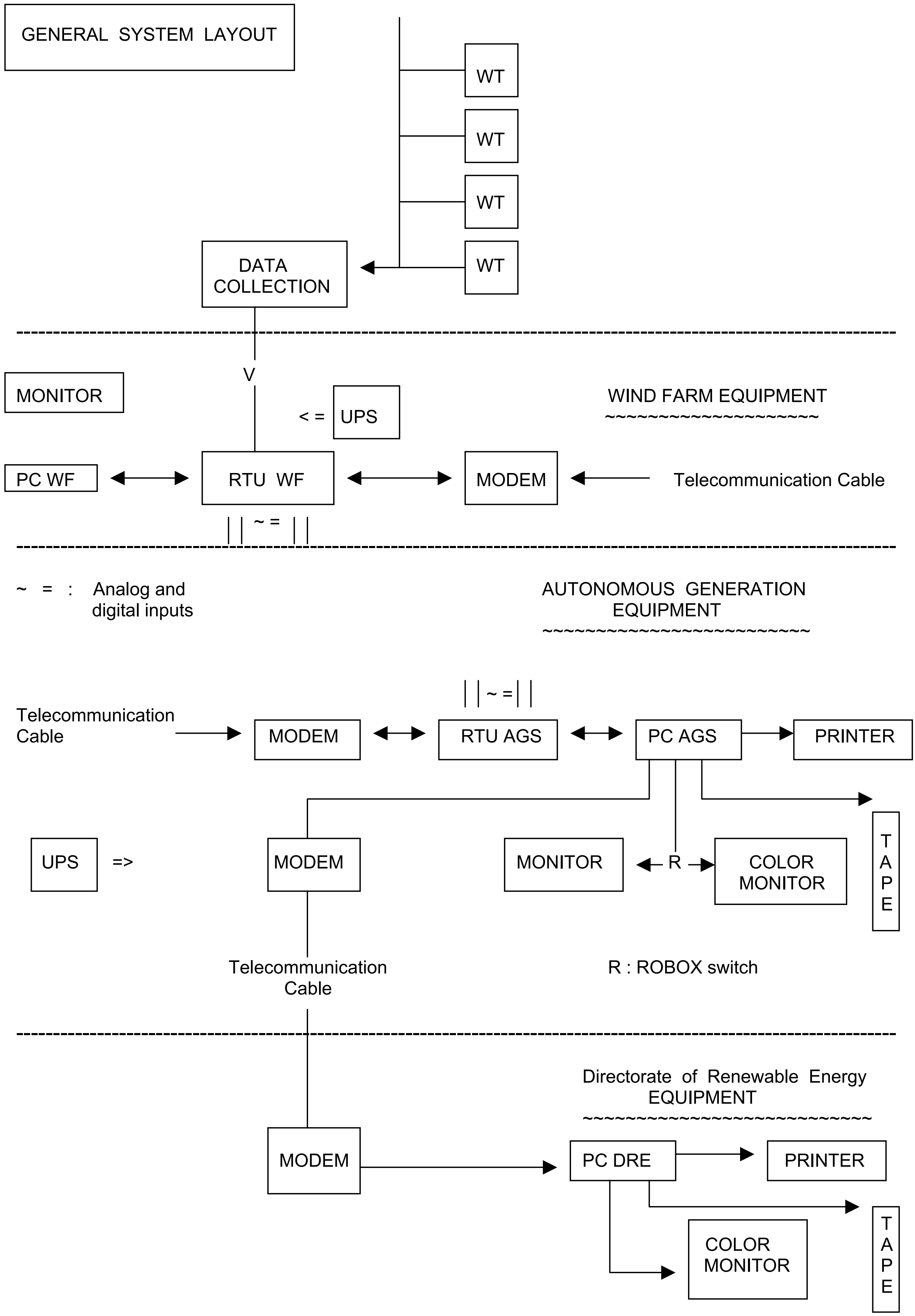
The wind turbines are automatically accessed into the system if they are available.

CONCLUSIONS

The EMS system is absolutely vital for the WTs function in an island's autonomous power grid, especially when the amount of electricity produced by the WTs is increased.

The AGS has to have a high reserve for the load increase or decrease, especially in the case of strong wind that may exceed the operational limit and stop the WTs function.

The statistical handling of the data in every AGS, will help us to evaluate the wind energy potential and have a better view for our future strategy not only in the existing WFs but also in other islands in the Hellenic territory.


GENERAL SYSTEM LAYOUT
WT
WT
WT
WT
DATA COLLECTION
V
MONITOR
< = UPS
WIND FARM EQUIPMENT
PC WF
RTU WF
MODEM
Telecommunication Cable
| | ~ = | |
~ = : Analog and digital inputs
AUTONOMOUS GENERATION EQUIPMENT
| | ~ = | |
Telecommunication Cable
MODEM
RTU AGS
PC AGS
PRINTER
UPS
=>
MODEM
MONITOR
R
COLOR MONITOR
TAPE
Telecommunication Cable
R : ROBOX switch
Directorate of Renewable Energy EQUIPMENT
MODEM
PC DRE
PRINTER
COLOR MONITOR
TAPE

LOAD MANAGEMENT ALGORITHM

The following algorithm is a method to manage the Load in wind farms.
It relies upon the equipment that exists in the area and gives all the necessary data to the operator in order to supervise and control the function of the wind turbines.
The approach used here is the combined operation with Diesel engines. The importance of Diesel engines is vital here because the wind farm is supposed to be installed in a Hellenic island. The conditions in such an area are dynamic and frequent changes in the air direction and speed are very usual. In order to avoid such problems and possible power outages in the island we assume the use of Diesel engines for the Power production during the time that the turbines are out of use. This can be done due to wind speed exceeding the minimum and maximum levels, which are set to 3.5 m/s and 24 m/s.

The first function of this algorithm is to establish the communication between wind farm and RTU. The following task is to check the working condition of the Diesel engines. After this check the operator gets from the instruments the diesel Power.
Furthermore the operator gets from his instruments the wind speed and if it is out of limits puts the wind turbines that operate at the moment out of use. If the wind is within the limits, the power from the wind turbines is calculated with the use of the following equation:

$$\mathbf{P = 0.5\ p\ A\ V^3}$$

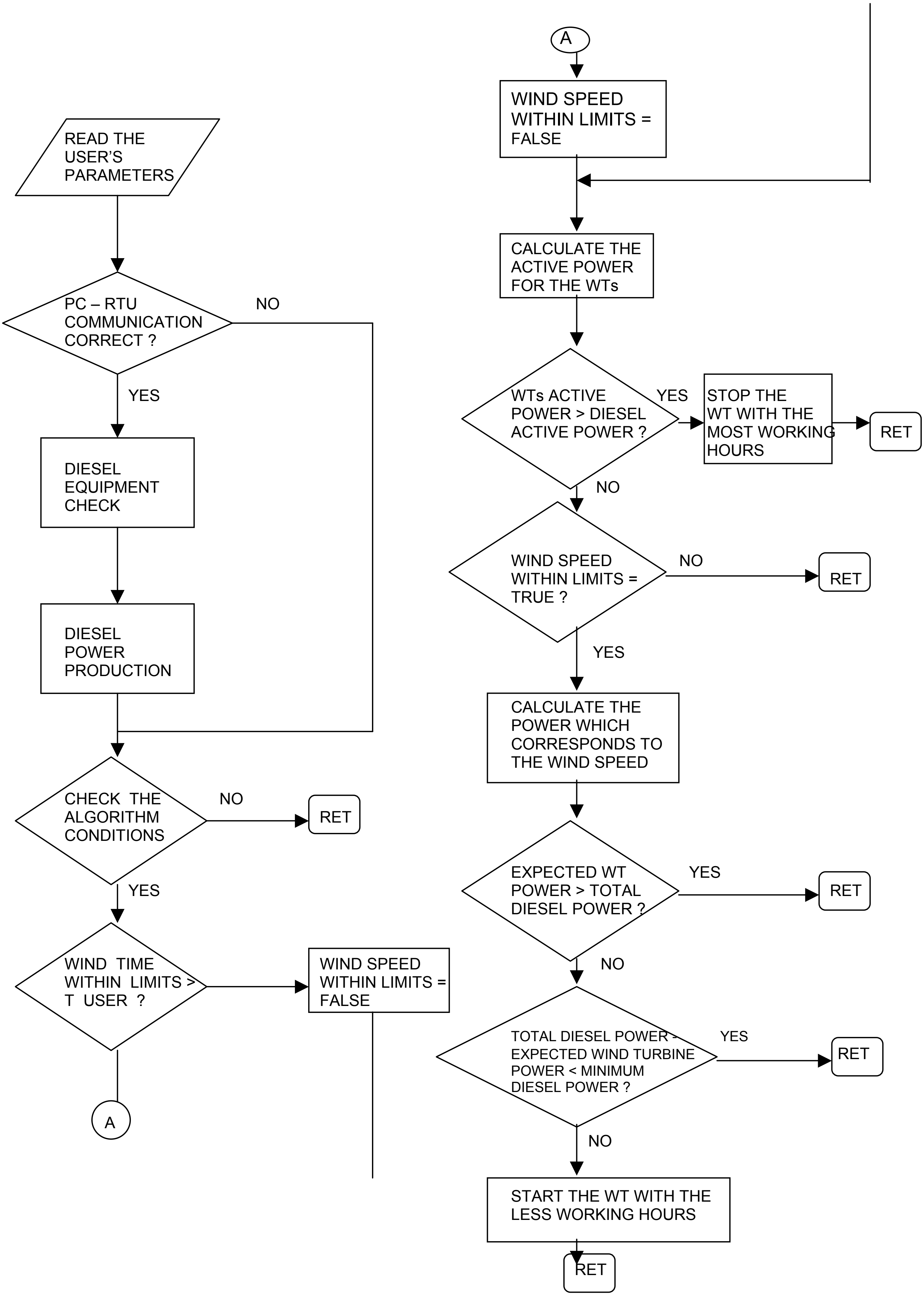
Where P is the produced power
0.5 Cp number of 0.5
p is the air density (1.25)
A is the rotor diameter (52 m)
V is the wind speed

This power is compared to the expected diesel power and the operator has the chance to see the efficiency of the wind turbines and decide which wind turbines will be operational and which will stop. The choice is done after the consideration of the working hours for each wind turbine.

If the operator is not satisfied with the production he compares the expected wind power with the minimum diesel power and decides upon to start another wind turbine.

The wind farm, which is assumed here consists of 10 wind turbines.

LOAD MANAGEMENT ALGORITHM FOR WIND FARMS



PROGRAMMING APPROACH

One of the main focus of this thesis is to turn the above algorithm into a program, which could be used with the simulation tools or the equipment of the wind farm and the measurements that come from each single device. One of the main problems was to choose the proper language for the programming approach. It is a wide belief that the knowledge of one programming language can lead to other languages with similar structure. My previous knowledge of Pascal was not enough in order to overcome the difficulties of this problem so I tried to get familiar with C and try to develop the program in this language.

One reason for C's success and staying power is that programmers like it. C combines subtlety and elegance with raw power and flexibility. It is a structured language that does not constraint. C is also a language that puts the programmer firmly in charge. C was created by a programmer for programmers. It is not the contrived product of a committee, but rather the outcome of programmers seeking a better programming language.

C is important for another reason. It is the gateway to the world's two other professional programming languages: C + + and Java. C + + is built upon C, and Java is built upon C + +. Thus, C is at the foundation of all modern programming, and knowledge of C is fundamental to the successful creation of high – performance, high – quality software.

The main aspects of the program rely upon the good communication between PC – RTU which is checked at the beginning of the algorithm. Also the user is prompted to check the good working conditions for the Diesel engines from the measurements he has available and then go on with the rest of the procedure.

The main aspect for the functionality of the wind turbines is the wind speed. At this speed there are two limits the upper (24 m/s) and the minimum level (3.5 m/s). If the wind is within these limits the power from the working wind turbines is given by the equation:

<u>P = 0.5 * 1.25 * 52 * windspeed * windspeed * windspeed</u>

The above equation stands for the working wind turbines. The number of working wind turbines is determined by the wind speed and the database, which is constructed into the program, and calculates the working hours for each wind turbine.

Furthermore there is a minimum Diesel power which has been set to 300 KW and this is to compare with the expected power from the wind turbines and start or stop one or some of them. Also there is a comparison with the random or expected power from the Diesel Electricity Production Couples. It is natural most of these data to be directly fed to the program by the special instruments that exist at the wind farm. Unfortunately at this case there is not the real data that could be used but the program could be easily used in order to work together with such equipment.

For more information about the following program there is an executable version that could be sent upon request.

```
#include <stdio.h>
#include <stdlib.h>
#include <time.h>


void init_gen();
void control();
void stop_generator(void);
void start_generator(void);
void power_compare(void);
int communication(void);
int diesel_func(void);
double wind_total(void);
double wind_speed(void);
double diesel_kw(void);


double dieselpower = 0;
double windpower = 0;
double windspeed = 0;
double windtotal = 0;
long gen_hours[10];
int  gen_run[10];


double dieselmin = 300;   /* minimum power produced by diesel */



int main(void)

{


printf("wind generator control, abort with ^C\n");

/* program can be stop by pressing control c */


/* assign working hours for wind generators */
init_gen();

/* loop execution of function for ever */

while (1)
     control();
```

```
}

void control(void)

/* program main function */


{


if (!communication())
  {
  puts("communication with diesel not available\n\r");
  return;
  }

if (!diesel_func())
   {
   puts("communication with diesel out of order\n\r");
   return;
   }


windspeed = wind_speed();

if ((windspeed < 3.5) || (windspeed > 24))
  {
  printf("wind speed (%f m/s) out of range\n", windspeed );
  stop_generator();
  return;
  }
else
  {
  windpower = (0.5 * 1.25 * 52 * windspeed * windspeed * windspeed) /
1000; /* in kw ? */
  printf("wind speed %f m/s, power which one wind generator can
produce: %f\n", windspeed, windpower);
  }

  dieselpower = diesel_kw();   /* get user input for diesel power */
  windtotal = wind_total();    /* determine number of active wind
generators */
  printf("Active Wind Generators: %f, Total Power of Wind Generators:
%f, Power of Diesel: %f\n", windtotal, windpower * windtotal,
dieselpower);
```

```
if ((windtotal * windpower) > dieselpower)
  {
  printf("total power of wind generators is greater then diesel power
(%f)\n", windtotal * windpower);
  return;
  }
else
  {

  windpower = (0.5 * 1.25 * 52 * windspeed * windspeed * windspeed
/1000) * windtotal;

  if ((dieselpower - windpower) < dieselmin)
    {
    printf("Diesel Power - Wind Generator Power < min. Diesel Power\n");
    return;
    }
  else
    {
    start_generator();
    return;
    }

  }

}


int communication(void)

/* determine if communication with wind generators is available */

{
srand(time(0));
return (int) rand() % 20;

/* return > 0 communication available
  return 0 communication NOT available */


}


int diesel_func(void)
```

```
/* determine if diesel is functional */

{

srand(time(0));
return (int) rand() % 20;

/* return > 0 diesel functional
   return 0 diesel NOT functional */


}

double diesel_kw(void)

/* get diesel power in kw from user input */

{

float  kw;
char   buf[10];


printf("enter diesel kw: ");

while (1)
     {

     scanf("%f", &kw, buf);

       if (kw > 0)
          {

          if (kw <= dieselmin)
             printf("input value must be greater than Diesel min. power %f,
enter diesel kw: ", dieselmin);
          else
             return (double) kw;

          }
       else
          printf("invalid input, enter diesel kw: ");

     }
}
```

```
double wind_speed(void)

{

srand(time(0));
return (double) (rand() % 3000) / 100;

/* calculate wind speed in 0-3000 cm per sec. */

}

void start_generator(void)

/* start wind generator with smalles amount of working hours */

{
long minhours = gen_hours[0];
int i,min = -1;

for (i = 0; i < 10; i++)
    {

    if ((gen_run[i] == 0) && (gen_hours[i] <= minhours))
      {
      minhours = gen_hours[i];
      min = i;
      }
    }

if (min == -1)
   printf("all wind generators running\n");
else
   {
   gen_run[min] = 1;
   printf("wind generator #%d with %D hours started\n", min + 1,
minhours);
   }


}

void stop_generator(void)

/* stop wind generator with most working hours */

{
```

```
long maxhours = 0;
int i,max = -1;

for (i=0; i < 10; i++)
    if ((gen_run[i] == 1) && (gen_hours[i] > maxhours))
       {
       maxhours = gen_hours[i];
       max = i;
       }

if (max == -1)
   printf("all wind generators stopped\n");
else
   {
   gen_run[max] = 0;
   printf("wind generator #%d with %D hours stopped\n", max + 1,
maxhours);
   }

}



double wind_total(void)

/* determine how many wind generators are active */

{

int i, total = 0;

for (i = 0; i < 10; i++)
    {

    if (gen_run[i] == 1)
       {
       total++;
       }
    }

return (double) total;

}


void init_gen(void)
```

```
/* intialize working hours of wind generators
   in the range from 0 to 300 hours           */


{

int i;


srand(time(0));

for (i=0; i < 10; gen_hours[i++] = rand() % 300)
    {
    gen_run[i-1] = 0;
    printf("wind generator %d - %D hours\n", i+1 , gen_hours[i-1]);
    }

}
```

CHAPTER 4

UPGRADE PROPOSALS FOR THE EXISTING ENERGY CONTROL SYSTEM

SYLLABUS

The operational life of a remote control system lasts from 10 – 15 years. The most important reasons that lead to the replacement of the system is the obsolescence of the equipment, the more rapid control of the controlled networks, maintenance difficulties regarding the software, the configured operation system etc. It is very important to take into consideration two major parts during the renewal of such a system. The first one is the design of the new system and the second is the alteration from the existing system to the new one. During the design we should be able to identify all the strong assets of the new system, the ability to incorporate a part of the old system and achieve a gradual modernisation, the gains from the old experience in order to overcome difficulties that we may have faced in the past. During the alteration of the remote control system the function of the ECS should be as less as possible influenced, and this depends on the extension of the work and the method used. It is vital to have a plan ready for this renewal, in order to maintain the functionality of the system, reduce the time needed, and avoid disturbing the operators. This plan should take into consideration all the major works and steps, the personnel involved, the time needed and the most critical functions.

USUAL PROBLEMS IN THE REMOTE CONTROL SYSTEMS

It is a fact that the rapid techniques in the design of the equipment oblige the producers to design new products as far as they can cover the production cost for the current equipment. This presupposes the production of new devices every 4 – 5 years. The older equipment is maintained for 6 – 8 years more from the manufacturers.

The equipment used in a remote control system is defined at the design stage that lasts at least 2 – 3 years before its operation, so there is a great risk for the equipment to be obsolescent before the 10 – 15 years of its operational life. Apart from that we have to take into consideration the increased maintenance cost that sometimes is above the acceptable levels.

A financial balance should take place in certain periods in order to compare the initial cost and the maintenance cost for the new and obsolescent equipment. The result could show that it is preferable to replace the current equipment although the manufacturer guarantees the maintenance of it. It is also common to identify problems because the personnel are not used to work on out of date and market equipment.

CONTROL CENTER INADEQUACY

At the design stage of the remote control system it is necessary to take into consideration the extension of the ECS (more substations, or data gathered) further than the operational life, so that the new functions could be easily adopt in the future.

Even if the designers pay close attention to the design of the system there is always a chance of mistakes that could lead to a malfunction of the system.

A periodical control should take place in order to assure that the quality is of the maximum possible level. As maximum level we could define the ability of the system to perform all the necessary functions in a time margin that allows the examination of all the alternative solutions. The maximum levels concern the equipment, software and operational environment.

For the time, availability and response time of the CPU the user should determine the data for the configuration level with a closer look to the point that refers to power outages. It is also important to pay attention during the reception controls in order to assure that the necessary values have been achieved in detail.

Furthermore a periodical control should be done in order to show if the real values are still satisfactory.

SOFTWARE MAINTENANCE

There are usually deficiencies in the software used in the remote control systems. These deficiencies become obvious after the first operational years of the system, when there is a need to input new function or more data. That is why the designer should be very careful in order to avoid the following situations:

- The software is developed in unusual programming language for the current PCs or for the manufacturer and this could cause problems to the personnel.
- There is a lack of software aids (software tools, e.g. assembler, compiler, test aids, utility programs etc.) in order to develop new programs.
- The operational system is inadequate to manage new input – output channels or new memory areas for the execution of new programs.
- There is poor written program documentation and poor readability.
- The programs are not correct structured and the software areas are interconnected without tolerance. In this case an

alteration to a block could cause malfunctions to the other blocks.

INSUFFICIENT DATABASES

It is obvious that the size of the electricity grid will increase during the operational life of the remote control system. Normally this increase is taken into consideration during the design stage of the system, but there are some cases that major alterations at the grid are not expected and the database does not have the right dimensions in order to receive a greater number of data or it cannot be extended in order to receive these data.

It is somehow interesting to reassure during the initial stage of the design that the database can be altered later on.

Other problems may occur due to the structure of the database which may not be flexible enough to define new data tables for new application programs.

The electricity grid is changing all the time from its nature, that is why there is the need for databases that can be renewed all the time in order to describe the network. This procedure should be easy, simple and not time consuming.

ALTERATIONS AT THE OPERATIONAL DEMANDS

During the lifetime of the system it is common to change the operational environment for different reasons such as:

- Change of responsibilities at the different levels due to a different structure of the company.
- The installation of new equipment at the generation stations (data recorders, oscillographs etc.).
- The need to exchange data through control centres that belong to other companies.

- The need to increase the operators at the control centres.
- The need to improve the graphical interface with the use of new monitors with higher resolution and 'Pan' and 'Zoom' capabilities.
- The need to show to the operators only synoptical data during power abnormalities in order to avoid an extreme number of messages and alarm signals, which make it very difficult to understand the cause of the problem and find the best solution.
- The need to transmit and receive data from other computer units that may belong to the data processing department or to the research department.

The current control centre may not be adequate to compensate with the new operational needs due to insufficient equipment or software.

SOLUTION METHOD
DETERMINATION OF THE DEMANDS

In order to upgrade an existing remote control system we have to face two major points :

a) The design of the new system.
b) The alteration from the current to the new system.

It is of great importance to define :

- All the strong assets of the new system.
- The ability to use a part of the current system and then to achieve the total integration of the new system.
- The advantages from past experiences that can be useful in order to overcome difficulties during the installation of the new system.

The determination of the demands is the first and probable most important phase in the upgrade of the system. A mistake at this phase could lead to serious functional and financial problems.

In order to define our demands from the system we have to answer two questions:

- Which are the operational needs now, at the near future and later on?
- Which are the reasons that lead us to upgrade the current system?

Finally there are two more questions that we have to answer :

- Which parts of the current system should we upgrade?
- Which is the time needed in order to have the new system operational?

At the previous parts there was a try to describe the different problems that may occur to a remote control system. Fortunately a current system will not face every problem but it is important to define and classify all the possible difficulties.

That is why the proper classification is the key to define the installation and upgrade demands of the system. The classification should have the same structure with the system and also have the same design:

- Data processing subsystem (real time systems installed at the control centre).
- Data transfer subsystem.
- Management subsystem (database creation, telecommunication network management, real time error and malfunction supervision, installation control, monitoring functions).

The close examination of the current limits helps to define the priorities for the upgrade and prepares the research for the operational demands. This is due to the knowledge we have obtained from the different problems.

DEFINEMENT OF THE POSSIBLE SOLUTIONS

There are many variations for the replacement or upgrade of a control system.

Some of these variations are :

1. Addition or replacement of the current monitors (VDUS) and peripherals.
2. Addition of front – end processors or replacement with new and more powerful.
3. Addition of new major PCs or replacement of the main PC with a newer and more powerful which has the same operating system or a new better one.
4. Replacement of all the data from the control centre into the current or new building.

The different choices depend on the following factors :

1. The formation (composition) of the current system.
2. The support from the company that provides the main PC.
3. The ability to replace the current PC with a new more powerful that uses a compatible operational system with the current one.
4. The ability to add a new device or replace current devices with new ones, which help the control centre to cover the new demands.
5. The ability of the PCs to work in a structured network, which will prevent the total failure of the remote control system.
6. The ability to use a big part of the software.

There are some cases when big EMS have been upgraded during a weekend with the installation of bigger and more powerful PCs, which have the ability to perform better regarding the network and safety. In other cases it is possible to convert a double composition to quad or a quad to a six unit system in order to increase the computing power. This is very easy to adopt when all the PCs are of the same type and manufacturer. It is also possible to increase the computing power by adding new PCs from different manufacturers or with different operating systems and connect them together at the same communication gates. Faster PCs, more PCs or more microprocessors can be connected in a LAN or through communication cables. This can be a very simple and cost effective upgrade method, only if the computers are of the same type, manufacturer, same operating system, same interfaces to the LAN. It can be more complicated if the control functions or interfaces are different.

UPGRADE PHASE

The operation of an ECS should be as less as possible influenced from the upgrade of the system. It is common that the problems are not taken into consideration before the alterations and they are understood later on by the operators. This depends on the extension of the project and the method used, but the transition phase could last from a few weeks to some years. The electricity companies rely heavily on the remote control systems in order to reassure the operation of the network, and every problem could be used in order to gain experience for the operators but also it should be overcome easily and effectively. So, it is very important to establish a strategy in order to achieve the best results during the upgrade phase and avoid most of the problems.

The most important targets that the company should have are :

- To maintain the functionality of the system.
- To reduce the time needed in order to achieve the upgrade of the system.
- To minimize the problems caused to the operators.

A strategy should be established from the beginning of the project. This strategy should determine all the major works and steps of the project. It is vital to use the best method in order to accomplish this particular task.

Additionally this strategy should identify all the personnel involved in the project. For example, maintenance personnel, operators, system engineers, and the role that everyone should play, their needs and their training.

The strategy should also give a guideline for the minimum operational standards that the system should maintain during the upgrade phase. As an example we could mention the time during the day that the system could be easily maintained or the most major functions that cannot be interrupted and the functions that take place during the power restoration procedure. At last, there should be a program to monitor the project and verify that the upgrade goals are being achieved. Of course, it is important for the project to be flexible and have the ability to alter some steps in order to conform to the needs that the engineers may face in the future.

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