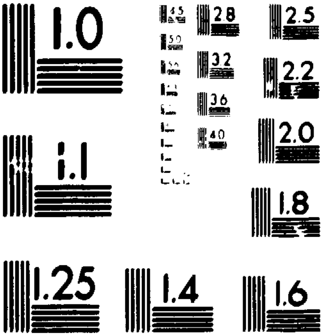


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No 2)

ENEL ENTE NAZIONALE PER L'ENERGIA ELETTRICA

ETDE-IT--92-29 .
DE92 506245

AN ENHANCED DISTRIBUTION AUTOMATION SYSTEM BASED ON NEW COMMUNICATION TECHNOLOGY AT ENEL

AN ENHANCED DISTRIBUTION AUTOMATION SYSTEM BASED ON NEW COMMUNICATION TECHNOLOGY AT ENEL

E. Comellini, R.Gargiuli, G. Gelli, R. Tonon -- ENEL Distribution Directorate
P. Mirandola -- ENEL Studies and Research Directorate

SUMMARY

After much investigatory work, ENEL has designed a new Distribution Automation System, based on line carrier communication technology, for providing an overall solution to the two most important aspects concerning the automation of on-line activities related to electricity distribution:
- remote control of MV power network
- MV and LV customer meter service automation.

The report describes the key choices that determined the architecture of the new system and the most important features of its main components, in view of
- an improvement of energy usage efficiency,
- a better supply service to the customers,
- an increased simplicity and transparency in the relationships with the customers.

FOREWORD

On the basis of an extensive research aimed at the assessment of the feasibility of a cost effective two way telecommunication system and of the experience gained during the eighties in the field of remote control of the primary distribution network -where new digital techniques were introduced {1}- and in the field of metering apparatus -where about 7 000 HV and MV customers were equipped with Ferraris meters associated with electronic devices for the application of multirate tariffs {2} {3}- Enel has designed a new Distribution Automation System aimed at:
- remote control of MV distribution network
- MV and LV customer meter service automation.

We decided to undertake this project for the following reasons.
- Times are ripe for the extension of the remote control techniques to the main nodes of the MV distribution network, in order to improve the efficiency and the quality of service.
- Times are also ripe, in our opinion, for the extension of automation techniques to the remaining part of ENEL's MV customers and to the largest LV customers, in order to allow the introduction of more sophisticated tariffs aiming at a more rational use of energy.
- Even though the bulk of Enel's LV customers have small consumptions and the gains attainable through automation of their meters are consequently reduced, the new Distribution Automation System has to be open also to a future application to these users, in order to achieve a better energy efficiency and to increase the effectiveness and transparency of the technical and commercial relationships with them.

Moreover Very Large Scale Integrated Microelectronics are likely to allow, in the near future, a sufficiently low level of costs to permit the application of the proposed solution even in the case of the smallest domestic users.

- On the Electricity Supply Industry standpoint, big advantages can be reached in terms of economy, efficiency and reliability through this broad systematic approach, whereas big risks would have to be run if each problem were solved on a case by case basis, which would undoubtedly bring about duplication of equipment, overlapping of functions and, in the long run, an unbearable strain on operation.
- On the standpoint of the Industry that supplies equipment and apparatus, our design provides the necessary framework where the various solutions can be developped and improved.

For sake of clarity, we have here subdivided the description of ENEL Distribution Automation System into the following Paragraphs:

- Paragraph 1 offers an overview of the structure and organization of ENEL distribution network;
- Paragraph 2 describes the facilities provided by the automation system;
- Paragraph 3 deals with the most important features of the telecommunication system;
- Paragraph 4 shows the architecture and the main functional aspects of the automation system;
- Paragraph 5 describes the equipment of the MV network, with special reference to the interface with the remote control system;
- Paragraph 6 describes the metering apparatus, developed for the customer service automation;
- Paragraph 7 gives an overview of present and future developments in this field;
- Paragraph 8 reports some general conclusions regarding the whole matter presented in the paper.

1. ENEL DISTRIBUTION NETWORK

1.1 STRUCTURE

ENEL distribution system (a schematic diagram is shown in Fig.1) includes three distinct networks at different voltage levels, namely HV (132-150 kV), MV (10, 15 and 20 kV) and LV (230/400 V) respectively.

The HV primary distribution network, energized by the transmission grid at 220-380 kV through the VHV/HV substations, feeds a number (≈ 1 200) of HV/MV primary substations and a number (≈ 700) of very large industrial customers. The total extension of the HV network is equal to ≈ 25 000 km.

The MV network, energized by the aforesaid primary HV/MV substations, feeds, in its turn, a number (≈ 270 000) of secondary MV/LV substations and pole mounted transformers, and a number (≈ 100 000) of large industrial customers. The total extension of the MV network is equal to ≈ 280 000 km.

The LV network, energized by the MV/LV transformers finally feeds both the bulk of domestic and residential customers (≈ 25 million) and the large LV customers (≈ 1 million). The total extension of the LV network is equal to ≈ 580 000 km.

With reference to the scopes of this report, we wish to evidence the fact that, even though Enel MV and LV networks have, in general, a meshed structure, they are always radially operated. That means that, by keeping open some switches, each HV/MV transformer supplies a limited portion of the MV network, as well as each MV/LV transformer supplies a limited portion of the LV network and, as a consequence, each MV or LV load is always supplied by one transformer only.

Moreover the protections are only associated to the circuit breakers installed in the HV/MV substations, as far as the MV network is concerned, and in the MV/LV substations, as far as the LV network is concerned. Consequently, a fault on a MV or LV network is always cleared by the circuit breaker located on the corresponding departure from the feeding substation; only at a later stage, through the operation of the switches located in the MV/LV substations of the MV network or along the lines of the LV network is possible to limit the outage extension.

1.2 ORGANIZATION

ENEL organization, in respect of distribution network operation is articulated into the following levels: District, Zone and Agency.
The District is responsible of the operation of the HV network and covers a region, with an average area of 12 000 km^2 and an average number of customers of about 1 million.
The Zone is a subdivision of the District, responsible for the operation of both MV and LV networks, and covers an average area of 1 800 km^2, with an average number of customers of about 160 000.
The Zone, in its turn, is generally subdivided into two, three or, in urban areas, even more Agencies, the Agency being the smallest unit in Enel's organization, which cooperates with the Zone in the operation of the MV and LV networks.
At present ENEL distribution organization includes 24 Districts, 171 Zones and 593 Agencies.

2. FACILITIES PROVIDED BY THE DISTRIBUTION AUTOMATION SYSTEM

The "Distribution Automation System", described in the following paragraphs, has been designed to offer a comprehensive range of new facilities related to two fundamental aspects: Network Automation, mainly aimed at the improvement of the quality of the electricity supply, and Customer Meter Service Automation, mainly aimed at the improvement of the technical and commercial relationships with the customers.

Facilities related to MV Network Automation

a) Real time updating of the state of connection of the network, dependent on the open/closed position of the switches.
b) Automatic sectionalizing of the faulty section of the network.
c) Automatic service restoration on the network sections not affected by a fault.
d) Remote execution of commands on network switches either for the prevention of situations that may involve service deterioration (i.e.: overloads) or for maintenance purposes.
e) Application of new enhanced strategies for voltage and reactive power control.
f) Collection and storage of data related to network operation for planning and engineering purposes.

Facilities related to Customer Meter Service Automation

a) Remote reading of consumption data according to a required time table, in order to eliminate:
  - any access to the metering apparatus, which becomes more and more difficult and expensive, particularly when the metering apparatus is installed in the customer's premises;
  - any account invoice based on the extimated consumption between two consecutive readings.
b) Application of time-of-day tariffs, based on the variation of daily and seasonal costs of energy.
c) Modulation of the power available to the user based on the variation of daily and seasonal costs of power.
d) Tripping of the circuit-breaker on board of the metering apparatus applied to domestic and residental LV customers, when the demand exceeds the set value of power.
e) Remote modification of the set value of power, in case of contractual variation of the subscribed power or reduction to a vital minimum for bad-payers, so as to eliminate any access for on-spot interventions.
f) Transitory remote reduction of the set value of power to cope with emergency contingencies of the electricity system, avoiding the complete cut off of the load.
g) Remote tripping of the circuit-breaker on board of the metering apparatus applied to domestic and residential LV customers, in case of termination of the supply contract.
h) Detection of frauds through the comparison between the energy delivered by each MV/LV transformer and the total energy consumed by the supplied customers and, in a similar way, between the energy delivered by each HV/MV transformer and the total energy consumed by the supplied MV customers and MV/LV transformers (this gives the network energy losses and consequently an evaluation of possible frauds and of their localization).
i) Diagnostic of the metering apparatus related to the functional aspects and to fraud protection.
l) Information on the quality of supply (number and duration of service interruptions).

m) Transmission of messages to the users related to service conditions (advance warnings of service interruptions) and to the commercial relati.mship (payment of invoices etc.).

3. TELECOMMUNICATION SYSTEM

3.1 CHOICE OF THE COMMUNICATION MEDIUM

The favourable results of much investigatory work, developed since 1982 with the aim of identifying the most important transmission parameters[(1)] of MV and LV distri-bution networks as a function of frequency and time, have led ENEL to adopt a line carrier system on the same MV and LV distribution networks.

The reasons behind this choice are the following.

- The availability of a data transmission link at each electricity delivery point, which does not require any additional dedicated physical structure (the electric connection also ensures the data transmission connection).
- The autonomy of ENEL's personnel for installation and maintenance tasks, without any need of co-ordination with the personnel of other undertakings.
- The utilization of a proprietary telecommunication system, which has always been considered mandatory for network operation, offers also a very good solution, for reasons of both reliability and availability, to customer meter service automation, which involves functions with a lower priority level.
- The adopted telecommunication system, as the electricity wires on which it is based, reaches any corner of the customer's premises, so opening the way to a new information service to the customer by the Electricity Utility.

Even though the carrier frequencies are used, since long time, on the VHV grid and HV networks, new problems arise when the same technique is applied on MV and LV networks.
In fact, in the case of VHV grid and HV networks, high frequency traps and by-passes are installed at both ends of each line, which avoid data transmission signals enter into the nodes of the power network and, consequently, make each data transmission link independent of the status of power circuit breakers or line-switches at line ends.
On the contrary, in distribution networks, costs of procurement and installation have made practically impossible the adoption of high frequencies traps and by-passes, and their absence is the origin of the following main problems.

The first problem regards the propagation and attenuation of the carrier frequency on a mismatched support (because of the variable impedance at the terminal points) and the noise produced by the electrical loads.
The solution given to this problem, according to the results of the above mentioned investigatory work, is briefly descri bed in the paragraph 3.2.

The second problem is related to the function of the remote control of the MV network which consists in isolating the faulty section of the network and in resupplying the parts not affected by the fault. In doing so, the system should have available the telecommunication system which, being coincident with the power network, is generally affected by the fault and by the operation of isolating the fault.
The solution to this problem is briefly described in paragraph 4.2.1 .

The third problem is related to the changement of configuration of the MV and LV networks, caused by the operation of the power switches, which involves a changement of configuration of the telecommunication system.
Indeed, because of the absence of high frequency traps and by-passes, the telecommunication nodes are coincident with those of the power network and, consequently, any operation of a power switch modifies the configuration of the telecommunication network.
The solution given to this problem is briefly described in paragraphs 4.2.2 and 4.2.3 .

---

(1) impedance, attenuation and cross-talk

In conclusion, the line carrier communication system on the MV and LV networks adopted by ENEL is completely new in respect to the one already known for the VHV grid and HV networks. We have called this system SITRED, that means "Integrated System for data Transmission on Electricity Distribution network".

3.2. MAIN FEATURES OF THE TELECOMMUNICATION SYSTEM (SITRED)

3.2.1 Modulation method

After evaluation of different modulation methods (i.e.: narrow-band, frequency-hopping and wide band), we have opted for the narrow band solution which is the simplest one and offers sufficiently good performances in respect of our requirements.

3.2.2 Transmission frequencies

We have chosen the following transmission frequencies:

≈ 72 kHz for the MV network

≈ 82 kHz for the LV network

which are within the range 9–95 kHz, allocated by CENELEC to the Electricity Supply Undertakings.
This choice was made as the best compromise between two opposite requirements:

- the reduction of the cost of components, which improves with the higher frequencies
- the reduction of attenuation, which improve with the lower frequencies.

The possible use of the same single chip modem on both MV and LV network has also been taken into account.
The above frequencies do not penetrate distribution transformers (both HV/MV and MV/LV) and not overcome, in general, the power switches when they are in open position. As a consequence of these facts and of the fact that ENEL's MV and LV networks are radially operated (see paragraph 1.1), signals are to be injected at the secondary side of each HV/MV and MV/LV transformer.
There are therefore as many independent data transmission networks as there are HV/MV transformers on the MV network and MV/LV transformers on the LV network.
The chosen frequencies do not penetrate power factor correction capacitors either, which therefore do not have an adverse effect on data transmission.

3.2.3 Coupling method

We have chosen the capacitive solution for coupling the transmission signals to the power networks because it appeared to be more efficient than the corresponding inductive solution and, consequently, able of reducing the output power level and the cost of the transmitters utilized on both MV and LV distribution networks.
As regards the modes of propagation, we use a phase to phase mode on the MV network and a phase to neutral mode on the LV network.
In conclusion we have adopted :

- a capacitive phase to phase coupling device on the MV network (Fig.2);
- a capacitive phase-to-neutral coupling device on the LV network.

The adopted MV solution does not affect the operation of directional earth protections in the HV/MV substations and minimizes the phenomena of cross-talk in correspondance of open switchgear.
On the point of view of construction, the MV coupling device is confined inside a small metallic oil filled box and may be connected to the MV network, through oil to air or oil to gas bushings, for installation in an air or in a gas insulated cubicle respectively.

3.2.4 Transmission power

Thanks to the efficiency of the above mentioned coupling devices, we have chosen a low level (≈ 1 W) for transmission power, both on the MV and LV networks.

Because signal attenuation, noise level and coupling impedance may vary in time, in an important way, as a consequence of the variations of the electrical loads and network configurations, we have adopted a store-and-forward procedure for retransmitting the signals, as a way to reach the most distant points even in the most difficult conditions.
Moreover, with reference to LV networks, which are more affected by electrical loads, we have implemented a procedure which allows a delay of even some hours in the transmission of signals, which is perfectly compatible with customer meter service automation and avoids transmission during the worst hours of the day (the hours of peak load).

3.2.5 Transmission rate

We have chosen the following transmission rates:
1,200 bit/s on MV network
600 bit/s on LV network.

These rates, even when allowance is made for the application of the store-and-forward procedure and for retrying the transmission of messages, can ensure the following performances:
- acquisition of signals from 100 remote controlled MV/LV substations in less than 1 minute
- acquisition of consumption data from 10 000 customer metering apparatus in less than 4 hours.

The above figures correspond to the average numbers of MV/LV substations and customers fed by a single primary substation and, consequently, the mentioned performances assume a general validity.

4. DISTRIBUTION AUTOMATION SYSTEM

4.1 ARCHITECTURE

In order to take the maximum advantage from all the possible synergies, the architecture of the "Distribution Automation System", shown in Fig.1, results from the integration of the following main sub-systems:
- the one for network automation, which is, in its turn, composed of:
  - STU {1}, for the remote control of the HV/MV substations (its application is already well developed);
  - STM {4}, for the remote control of the MV/LV installations (its development is underway);
- the one (ISU) for customer service automation (its development is now in the initial phase).

STU and STM constitute in reality a single sub-system for network automation, because STM has been conceived as a functional extension of STU.
According to the organization constraints (See paragraph 1.2), the Operative Center responsible for the operation of the HV network is located at the center of the District, whilst the Operative Center responsible for the operation of the MV and LV networks is located at the center of the Zone.
In the data transmission network, the HV/MV substations are directly connected, through proprietary multi-point channels (carrier frequencies on the HV lines or radio links), to the centers of Zone, which are, in their turn, connected, through both point-to-point proprietary channels and the public packet network, to the center of District (the use of proprietary channels is mandatory in Enel for the data transmission strictly related to the operation of the network).
In this way the whole flow of information, concerning the remote control of the HV/MV substations, passes through the centers of the Zones and may reach the center of the District. This gives the system a great flexibility because, in emergency conditions, the functions of the centers of District and Zone may be interchanged.

As it has already been said, the sub-system for customer meter service automation has been strongly integrated with that for network automation.
The information from the LV customers is taken to the MV/LV installation which, if remote controlled, adds the data of this function; this information is taken to the HV/MV substation, where the data coming from the MV users are also added.

The whole information is then taken to the centre of Zone where it is divided into two separate parts according to the nature of the data:

- the data, related to the network automation, are given to the sub-system for network control, even when they derive from the basic activity of interrogation of metering apparatus (See paragraph 4.2.4), that allow to detect the changes in the state of the line switches; these data can be elaborated and recorded both at the center of Zone and at the center of District.
- the data related to the customer meter service automation are sent to the computer of the ISU sub-system, which is generally located at the center of District and constitutes an interface towards the existing host computer that performs all the commercial functions.

The central computer of the sub-system for customer meter service automation (ISU) is responsible for the management of a data base which allows to associate the identification code of each customer, utilized by the host computer, with the address utilized by the Distribution Automation System for the same customer, which (See paragraph 4.2.3) is defined in relation to the structure of the distribution network.
The ISU computer receives from the host computer the orders related to the operations to be performed (readings of meters, variations of the maximum demand available to the users, activations and disactivations of electricity supply, etc.) and provides for their execution. It receives from the sub-system, devoted to network automation, the information regarding the state of connection of the MV and LV networks, necessary to adress the customers.

In addition to the above mentioned processing resources located at the centers of District and Zone, the architecture of the Distribution Automation System also includes the equipment described below.

The ACP apparatus (Fig.3), is located in each HV/MV substation and performs the following functions:

-- data transmission (SITRED) with the MV and LV networks fed by the substation through the coupling devices (Fig.2) connected to the MV bus-bars;
-- data transmission with the computer in the center of Zone;
-- local data exchange, through a suitable field bus, with the digital protection and control devices, located on board of each departure of the same HV/MV substation, so making no longer necessary the remote terminal unit, so far used for the remote control of HV/MV substations;
-- logical functions related to remote control of the network and to customer meter service automation.

The ACS apparatus (Fig.4), is located in each MV/LV installation and performs the following functions:

-- data transmission (SITRED) on the MV network, through a suitable coupling device (Fig.2), external to the apparatus and connected to the MV bus-bars;
-- data transmission (SITRED) on the LV network through a coupling device internal to the apparatus and connected to the LV bus-bars;
-- local data exchange with the unit UPT, also located in the MV/LV installation;
-- logical functions related to the control of the network and to the customer service automation.

The UPT apparatus, is located only in the MV/LV installations subjected to remote control (about 10% of the total) (See paragraph 5), where it performs the classical functions of executing the operational commands and of transmitting the state of the MV line switches.

The electronic unit associated to the metering apparatus (See paragraph 6) of each MV and LV customer, performs data processing and communication functions.
Communication functions also include the communication towards an electronic device that the customer can install in its own premises, to display information about energy consumption and other messages sent by ENEL and, in the most sophisticated versions, also to perform an activity of optimization of the demand according to multirate tariffs.
Whilst, a dedicated optical fiber is used for the connection of the MV metering apparatus to the customer electronic device, the same SITRED system performs also the task of data transmission towards the electronic device possibly installed in LV customer's premises (Paragraphs 4.2.5 and 4.2.8).

4.2. MAIN FUNCTIONAL ASPECTS

4.2.1 Automatic sectionalizing of faulty sections

Any fault on the MV network cuts the transmission link towards the parts situated downstream, with consequent difficulties for the STM sub-system, which should sectionalize the faulty section and resupply the sections not affected by the fault. To overcome these difficulties, we have assigned, as here shown, a limited automatic activity to the UPT apparatus.
Two main procedures have been defined depending on the presence of fault detectors in the nodes of the MV network.

Automatic sectionalizing without fault detectors

As it will be better illustrated in Paragraph 5, we use, in the remote controlled MV/LV substations, SF6 insulated switchgear which has built, in the MV bushings, voltage detectors, that are devices capable of signalling wether the terminal, to which they are applied, is alive or not.
A typical MV/LV installation includes two line switches (S1, S2) and one transformer switch (S3) (See Fig. 5a) and each terminal is equipped with a voltage detector: V1, V2 and V3 respectively; the voltage detector V3, applied to the transformer switch bushing, is used as an indicator of the presence of voltage on the MV bus-bars.
The procedure for the automatic sectionalizing is based on the implementation of two simple rules by the UPT located in each MV/LV installation.

- α) When the voltage detector of a line switch and the voltage detector of the transformer switch indicate absence of voltage for a duration higher than an established value τ_1, UPT commands the opening of the line switch.
- β) When the voltage detector of a line switch indicates the presence of voltage and the voltage detector of the transformer switch indicates the absence of voltage, for an established period of time τ_2, UPT commands the closing of the corresponding line switch.

Let's consider, as an example, a radially operated feeder supplying, for instance, 3 MV/LV substations, each of them provided with a UPT implementing the above mentioned rules.
Let's also suppose that a permanent fault occurs on the feeder section "c" (Fig.5b).
Because of the fault, the circuit-breaker-that protects the terminal of the corresponding feeder in the HV/MV substation-opens, so deenergizing all the feeder sections and cutting the communication link between the STM and all the UPT's.
According to the rule "α", each UPT commands (after the time τ_1) the opening of all the line switches so that, when the circuit breaker (after a delay higher than τ_1) recloses, the feeder section "a" is re-energized.
According to the rule "β", UPT1 commands, after the time τ_2, the closing of the line switch S11, recovering the communication link with the same UPT1.
It is therefore possible to command, from the STM, the reclosure of the line switch S12, so re-energizing the feeder section "b".
The above procedure is repeated by UPT2 until the line switch S22 is reclosed by a command sent from STM, so re-energizing the feeder section "c".
Being the feeder section "c" affected by the fault, the closing of the line switch S22 causes a new trip of the protection of the feeder departure in the HV/MV substation and consequently the opening of the corresponding circuit breaker.
The fact that the protection tripping is immediately consequent to the closing of the line switch S22 allows the identification of the section "c", as the one affected by the fault.

The aforesaid procedure is then repeated once again, but is stopped before the reclosure of the switch S22, so that the faulty section is isolated.
The above example is very simple, because the MV nodes here considered are of the simplest form; however even with MV nodes having a much greater number of departures, the procedure is simple and sure because all the decisions regarding the way to resupply the network are taken and actuated by STM, while the automatic operations performed directly by the UPT's are restricted to those necessary to re-energize each node once a line at its periphery is become alive, so re-establishing the communication link.

Automatic sectionalizing with fault detectors

In Enel we may use, on the line departures from the MV nodes of an underground network, fault detectors composed of two current transformers on two phases and a current transformer embracing the three phases; they are capable to detect phase to phase and phase to ground faults.
In this case the procedure to identify the section of the feeder affected by a fault is based on an interchange of information between two consecutive UPT's.
By referring to the same example of the previous paragraph, the interchange of data can be summarized as follows.

- UPT1, whose fault detectors have been activated by the fault, receives the information from UPT2 that also the fault detectors of the MV/LV substation 2 have been activated by the fault.
  As a consequence UPT1 comes to the conclusion that the fault is not on the line connecting the MV/LV installations 1 and 2.
- On the contrary, UPT2 either receives the information from UPT3 that the fault detectors in the MV/LV installation 3 have not been activated by the fault (when the fault does not interrupt the telecomunication link) or does not receive any information from UPT3 (when the fault interrupts the telecommunication link).
  In any case, UPT2 comes to the conclusion that the fault is on the line connecting the substations 2 and 3 and, consequently, commands the opening of the line switch S22.

When the circuit breaker located at the feeder departure in the HV/MV substation recloses, the part of the network not affected by the fault is immediatly resupplied.

4.2.2 Network configuration

For sake of clarity, we distinguish two kinds of distribution network configuration.

a) Structural configuration, corresponding to the network lay-out that includes the electrical lines and the nodes and, for each node, all the switching apparatus present in the node and the way in which each apparatus is connected to the others and to the lines reaching the node.
Structural configuration does not take into account the open or closed position of the switching apparatus and therefore does not change during network operation, but only in occasion of works (when a line or a node is added to the network)

b) Operational configuration, corresponding to the structu-ral configuration when account is also taken of the open/closed position of each switching apparatus.

4.2.3. Addressing method

As far as customer service automation is concerned, a suitable method of addressing LV metering apparatus has been introduced.
This method, described in the following, represents one of the most important hinges of the automation system, as it offers a number of conspicuous advantages on both technical and economical points of view.

While the MV network is described in the usual way of nodes and branches, the LV network has been described by sections; section being a part of the LV network which cannot been divided into two or more different parts by the operation of line switches.
Consequently, a *section* can be defined as a portion of the LV network, which is limited by a number of line switches in respect of the remaining part of the network and does not include, inside itself, any further line switch.
As, in general, several LV metering apparatus are connected to a *section*, we decided to give them an address, composed of two parts:

- the number of the section, called "address header"
- the number of the metering apparatus within the section, called "sub-address".

In practice, the address is loaded into the electronic unit of the metering apparatus (See chapter 6) at the moment when the same electronic unit is activated.

The above method of addressing offers the following advantages.

a) As each *section* is connected to a certain transformer, all the metering apparatus of the *section* are connected to the same transformer.
Consequently, we have not to interrogate all of them to ascertain that the *section* is connected, being enough to interrogate only one of them.
In fact, if it replies, the *section* and, therefore, all the meters of the *section* are connected; if not, the *section* and, therefore, all the meters of the *section* are not connected.
In this way, the updating of the state of connection of the network is speeded up as much as possible.

b) By reserving the number 1, within a *section*, (the numbers 2 and 3 are used as back-ups) for addressing a metering apparatus particularly well located for data transmission, namely in proximity of the main wire, possibly at the center of the *section*, we can identify the most suitable metering apparatus (we call it *"master of the section"*) to be used as relay for retransmitting messages to the other metering apparatus in the same sections or to the master of another section.
Taking into account the characteristics of SITRED transmission given in paragraph 3.3 and the usual lenghts of the sections in our LV network, it can be deduced that:
- all the metering apparatus of a *section* are reached by a message transmitted by the master of the same section;
- the *master of section* of a certain *section* is reached by the messages transmitted by the *masters of section* of the contiguous sections.

c) In order to be able to manage all the activities required by customer service automation, the data base of the ACS apparatus, located in a MV/LV installation, does not require the information concerning the various metering apparatus of the customers supplied by the corresponding transformer, the following information being enough:
- the list of adresses of the sections which can be supplied by the same transformer;
- for each of these sections the number of metering apparatus connected to it;
- a table giving the structural configuration of all the said sections (that is the way in which they can be connected between them and with the MT/BT substations).

In this way all the problems concerning storage, handling and updating of a large data base are completely avoided, with great benefits in respect of the simplicity, economy and reliability of the system.

d) Another important advantage obtained by this method of adressing is the management, by the head of the section, of the data transmission from each metering apparatus to the optional electronic device of the respective LV customer.

4.2.4 Message routing

Every message transmitted from the center has to bear, further to the adress corresponding to its final destination, also the indication of the route to be followed.

Taking into account the fact that the MV and LV networks are always radially operated, this route is unique and is defined by the HV/MV substation and by the MV/LV substation (in case of LV users) supplying, at the moment of data transmission, the considered user (or the considered substation, in case of messages of the network control system).
In the route indication, the adresses of some intermediate MV nodes and of the masters of some intermediate LV sections, to be used as relays in the store and foreward procedure, are also included.
As a consequence the message routing is strictly dependent on the updated knowledge of the operational configuration of both the MV and LV networks, which lies in the STM sub-system and is obtained through the following main steps.

- Loading of the structural configuration into the STM data base by another data base, resident in the host computer shown in Fig.1.
- Updating of the status of the MV line switches through the activity performed by the same STM to support the remote control of the MV network, taking also into account the basic activity of interrogation performed by the ACP apparatus located in the HV/MV substation on the MV nodes supplied by it.
- Updating of the status of the LV line switches through the basic activity of interrogation performed by the ACS apparatus, located in the MV/LV installation, on the masters of the sections which are supplied by it. (See paragraph 4.2.5).

4.2.5 Basic activity performed by the ACS apparatus

Each ACS apparatus performs, during the day, a cyclic interrogation exclusively directed to the masters of the sections, which are either supplied by the MV/LV transformer located in the same substation (section of the supplied network), or connected, through an open switch, to a supplied section (section at the outside periphery of the supplied network).

Interrogation of the master of a section of the supplied network

When a message of interrogation is sent by the ACS to the master of a section, chosen among those known, by the previous basic activity, to be supplied by the MV/LV transformer in the same substation, two possible events may follow.

A1) The "master" replies to ACS, so confirming that the section is still connected to the transformer. In this case ACS sends a new message to the "master" of the section in order to start a procedure aimed at the updating of the information contained in the customer's electronic device (Paragraphs 4.1 and 4.2.8). This procedure allots a well defined period of time to each metering apparatus of the section to send the data to the respective customer's electronic device. At the end of this procedure (whose duration is known by ACS on the basis of the number of users connected to the section), ACS proceeds to the interrogation of the "master" of another section.

A2) The "master" does not reply, so allowing ACS to recognize that the section is no longer connected to the transformer. In this case, ACS stores in its memory this information and puts itself in an "alarm status" in order to allow the ACP apparatus, to gather the same information (1) and to transmit it to STM to update the operational configuration of the network.

Interrogation of the master of a section at the outside periphery of the supplied network

When a message of interrogation is sent by the ACS to the master of a section known, by the previous basic activity, to be located at the outside periphery of the supplied network, two possible events may follow:

B1) the "master" does not reply to ACS, so confirming that the section is still not connected to the transformer;

B2) the "master" replies, so allowing ACS to recognize that the section, previously not supplied, is now connected to the transformer.

While in the first case (B1), ACS proceeds to interrogate the "master" of another section, in the second case (B2), ACS performs the same operations described in the previous item A2 for updating the operational configuration of STM. In addition, ACS resets the internal clocks of the metering apparatus of the section, which may not, for reasons of cost, be provided with a back-up supply source and which are stopped when the LV section is transferred from the network supplied by a transformer to that supplied by another (this transfer, to avoid the parallel operation of two transformers, requires a short outage of the section).

4.2.6 Remote reading of LV customer meters

Once a day, starting at 00:00 a.m., each ACS apparatus interrupts the basic activity, described in the previous paragraph 4.2.5, and starts a new polling procedure concerning the reading of the data in the memory of all the metering apparatus of the customers supplied by the corresponding transformer, aimed at the acquisition of:

- autodiagnostic information produced by the same metering apparatus;
- data consumption, only for the metering apparatus for which the invoicing period has ended at the midnight of the previous day (the terminal dates of the invoicing periods are stored in the memory of the metering apparatus).

---

(1)
ACP performs a similar cyclic procedure, concerning ACS's, which are fed or can be fed by the transformers, installed in the primary substation.

These messages, coming from the LV metering apparatus, are temporarely stored in the ACS memory, from which they are periodically taken by a parallel procedure performed by ACP on the ACS's of the supplied MV network. The ACP apparatus, in its turn, sends these data to the central ISU computer which directly utilizes the diagnostic data for the technical management of the metering apparatus and sends the data of consumption to the commercial computer where they are used for invoicing.

4.2.7 Transmission of commands

When the host computer dedicated to the commercial procedures, receives a request from a customer, involving a modification of some characteristics of the metering apparatus (i.e.: change of subscribed demand, contract termination, etc..), it sends the request to the ISU sub-system, devoted to its automatic execution.

The ISU sub-system firstly converts the identification code of the customer, used by the host computer, into the address used by the Distribution Automation System (Paragraph 4.2.3) and, successively, adds the routing (Paragraph 4.2.4) on the basis of the information continously updated by the network automation system.

When the message is sent, the metering apparatus replies to confirm the correct acquisition of the request; in very exceptional conditions, on the LV network, the message may require more trials to arrive at 'estination, or even to be delayed for a few hours to wait for better transmission conditions.

For this reason an immediate acqisition of the command cannot always be guaranteed and we have established a procedure which allows to associate at each command the time of execution, which, as a rule, is chosen sufficiently far from the time of transmission.

4.2.8 Customer interface towards home and building automation systems

The data link between LV meters and the MV/LV substation provides an information flow that propagates on the wires and can be received inside the customer premises.

The communication protocol, together with a continuous sequential polling, enables the sharing of the channel among all transitters, i.e. all energy meters, of the the portion of LV network supplied by the substation.

In this way the informaion flowing to a customer can be refreshed at a rate acceptable for practical utilizations.

An appropriate selection of data makes possible a powerful interface and a clear interaction with the customer, which can play an important role in the control of the demand for energy preservation, taking into account that, in a near future, an effective start-up is expected for home and building automation.

In the present time, international projects are in progress or in adavanced stage, in order to prepare a global proposal for standardization, with reference to functions, devices, communication media and protocols required in home and building automation.

Recently, connection to the ESPRIT Project n. 2431, concerning home automation system, has been established with the aim of a better integration of both utility and customer sides.

If this purpose is achieved, the information flow coming from the utility will be presented to the customer in a very understandable way and will directly influence the energy consumption through the rather sophisticated load control provided by home automation. Moreover, being the connection potentially bidirectional, these services may be further extended in the future.

As a first step, a powerful display has been conceived, based on a television set, and a study prototype has been developed.

The TV set, provided with a line receiver and the teletext facility under a simple controller, becomes a powerful device that can merge general information, broadcast by television, with specific data coming from the meter.

This window, opened on the electrical energy problems, can be accomotated in the consumer's premises, in a more accessible position than the meter itself. Through this window the customer will be get informed of different events (general, specific, technical, contractual etc.) and helped in the difficult task of saving energy.

5. MV/LV SUBSTATIONS: INTERFACE BETWEEN THE POWER COMPONENTS AND THE AUTOMATION SYSTEM

We have decided to use in the MV/LV remote controlled substations, only SF6 insulated motor driven switchgear. Because the masses of the moving parts of this switchgear are much ligther than those of the air insulated switchgear, the power of the motor and the capacity of the battery are reduced.
Indeed we use 300 watt 24 Vdc motors and 15 Ah batteries.
ENEL standards provide three, four and 5 switches for the same switchgear unit, with the possibility of connecting two units together in exceptional cases.
The battery and the battery charger are allocated on the SF6 switchgear and, further to the motors, they supply the voltage and fault detectors, the UPT and ACS apparatus; the a.c. supply of the battery charger comes from the LV side of the MV/LV transformer.
On the front of the SF6 switchgear a rail is located supporting the signal and command wiring coming from each switch and going to a common connector for the whole unit.
The same rail supports also individual connectors in correspondence of each switch, for the signals coming from the fault and voltage detectors of the same switch, which are allocated outside the unit.
As regards the transmission of signals, commands, data and ac/dc auxiliary power, the various pieces of equipment and apparatus are connected as shown in the diagram of Fig.6.
A similar solution has also been adopted for pole mounted switchgear, where the SF6 insulated solution provides for a higher degree of reliability in respect of bad weather conditions (Fig. 7). In this case the UPT and ACS apparatus as well as the battery and battery charger are located inside a waterproof sealed bottle which is undergrounded to limit the extent of thermal variations.
As a general rule all the equipment and apparatus are designed to make easy their installation and maintenance.
Indeed, as already shown, the wiring of the switchgear is prefabricated and is connected to the apparatus through standard connectors and prefabricated wires which require during installation and maintenance only plug-in operations.

6. METERING APPARATUS

6.1. GENERAL CHOICES

6.1.1 General

In the design of the Distribution Automation System, ENEL has made a radical revision of all the metering apparatus used for MV and LV customers, including measurement transformers, with the following scopes:
- reduction of tampering possibilities;
- reduction of the interventions on the user connections because of variations of contractual parameters (for instance an increase in the subscribed power). This has been achieved by enlarging the ranges of utilization of the various components and through a better coordination between them (in particular by the adoption of the same ranges of utilization for meters and measuring transformers);
- capability of the equipment for the MV user's connections to operate both at the present value of voltage and at a future possible level of 20 KV, thus making easier the transition of a number of Enel's networks, now operating at lower voltages, to this last value;
- display of the real values of active (kWh) and reactive (kVARh) energy measurements, for a better comprehension of the readings by the customer (in the previous apparatus the readings had to be multiplied by a constant).

Enel exerted a significant effort for the co-ordination of the designs of the different system components by the respective Manufacturers, to achieve the goals set for the automation system.

6.1.2 Meters

Taking into account that:
- all the facilities provided by the automation system are independent from the electro-mechanical or electronic technology adopted for energy measurement;
- the minimization of the industrial risks is essential for all new projects involving widespread application, particularly in this case, where also the relasionship with the user is at stake;

we have decided to keep, at least for the moment, the conventional electromechanical technology (Ferraris meter) for the energy measurement and to use the digital- electronic technology only for the additional functions, which are therefore performed by a device, closly associated to the meter, as is shown in the following.
This hybrid solution has the advantage, in comparison with a fully electronic solution, of keeping the measure of the total energy consumption in case of failure of the electronic device, thus avoding obvious strains in the relationship with the user.
In fact, Ferraris meters have achieved, through an almost secular evolution, a very high reliability level (less than a failure per year every 10 000 units) and a low cost.
On the other hand, the adopted solution is open to the future introduction of electronic meters {5}, once they have reached reliability and cost levels at least comparable to those of Ferraris meters.
The solution adopted by ENEL "Integrated Metering Apparatus" *integrates* all the required components in a fully closed and sealed single case, made of glass reinforced resin.
With reference to the two major categories, into which Enel's customers are divided, these components are:

- for the bulk of Enel's customers, that are the domestic and residential LV customers:
  - a meter, for measurement of the active energy;
  - a thermomagnetic circuit-breaker, for protection of the upstream circuit (and for limitation of the maximum demand below the contractual value when the electronic unit is not included in the metering apparatus);
  - an electronic unit, for data processing and communication;
- for the large LV consumers and for all MV consumers:
  - two meters, for measurement of active and reactive energy;
  - an electronic unit, for data processing and communication.

To achieve the goal of a reduced susceptibility against attempts of electricity tampering, these precautions have been taken in the design:

- the structure and material of the case do not permit the introduction of external bodies without leaving well visible tracks;
- an appropriate metal screen inside the case provides for a better protection against electro-magnetic interferences.

6.1.3 Electronic units

The electronic unit is plug from the back into the case of the Integrated Metering Apparatus, so that:

- the same seal guarantees the integrity of the installation both of the whole apparatus and of the electronic unit;
- during normal operation, in case of fault, the electronic unit can be replaced without removing the whole metering apparatus (the reliability of these units is unlikely to reach the level of the Ferraris meters);
- during the period necessary for the extension of the automation system to all the customers, the integrated metering apparatus, required to replace a meter of the old type, may be installed without the electronic unit, which may be added at a later stage, when the automation system is activated in the area where the integrated metering apparatus is installed.

In fact the automation system will be activated according a well defined temporal plan in homogeneous areas, whereas the need for replacement of the old meters arises at random in the system.
The chosen solution permits to delay the investment for implementing the functions of automation until the moment when these functions can become operative and can therefore produced the expected gains.
Moreover, this solution will permit a step-by-step initial application program, suitable to wait for the industrial stabilization of the electronic product, particularly critical for LV domestic customers, for which reliability and costs to be achieved dictate the recourse to dedicated very large scale integration electronic components.

6.1.4 Connection between Ferraris meters and electronic units

For the transmission of the data of consumption from the Ferraris meter to the electronic unit within the same case, each Ferraris meter is equipped with the following three elements (Fig. 8):

- a sectoral wheel for metering pulse generation;

- two optical fibers for the transport of light from the periphery of the sectoral wheel to the connector described below;
- an optical connector, installed on the surface of the case, towards a corresponding connector of the electronic unit.

The sectoral wheel is added to the mechanism driving the mechanical register of the meter and its periphery is divided into a number of sectors alternately full and void, so that they are or completly transparent or opaque to light.
One extremity of each optical fiber is fixed in correspondance of the periphery of the wheel, in a face to face configuration, whilst the other extremity is fastened to the connector.
The light beam, generated by a photoemitter inserted in the connector of the electronic unit, is brought to periphery of the sectoral wheel through one of the two optical fibers and may or may not go through the wheel according to the wheel position .
The other optical fiber is dedicated to transmit the same light beam to a photoreceiver, also inserted in the connector of the electronic unit.
In this way light pulses are produced, each of which corresponds to a well defined quantity of energy, which has been made independent from the constant of the meter by a suitable design of the driving mechanism and of the sectoral disk.

Only low-cost high reliability passive elements are installed in the meter case, while the active elements are placed inside the electronic unit.

6.2. CHOICES PROPER TO EACH CATEGORY OF USERS

6.2.1 General

The main categories of Enel's customers, the various types of Integrated Metering Apparatus and the corresponding electronic units are shown in Fig. 9 as a function of the subscribed demand.
The principal subdivision is the following:

- domestic and residential LV customers with a subscribed power not greater than 15 KW; this category includes the bulk of Enel's customers (more than 25 million);
- large LV customers with a subscribed power greater than 15 kW and MV consumers;

6.2.2 Domestic and commercial LV customers

The following two types of Integrated Metering Apparatus have been developed respectively for:
- single-phase customers: GMY (Fig. 10);
- three-phase customers: GTY (Fig. 11);

The thermomagnetic circuit-breakers installed inside the GMY and the GTY cases are new products, designed to meet the requirements below described.

- Limitation of the maximum power available to the user by the thermal relay of the circuit breaker when the apparatus operates without the electronic unit (the apparatus shall be chosen in this case according to the power subscribed by the user).
- Elimination of the intervention of the thermal relay, once the electronic unit is inserted, and actuation of the tripping pulse emitted by the electronic unit, when the demand exceeds the set value (the apparatus is then no longer related to the power subscribed by the user).
  As it has already been said, the set value can be changed from a remote center following a contractual variation, an emergency in the supply etc.;
- Actuation of a continous tripping signal emitted by the electronic unit, in case of termination of the contract of supply or of excessive delay in payment, preventing the customer from switching on the circuit breaker.

With reference to these two last functions, the new circuit-breaker has been provided with a tripping coil ensuring the possibility of control by the electronic unit.

The electronic unit is the same for GMY and GTY. but it has been developed into two different versions, called UEP and UEPR (reduced UEP).

The electronic unit UEP, is used in an Integrated Metering Apparatus when it is installed inside the consumer premises, while the electronic unit UEPR is used in an integrated metering apparatus when it is installed on a central board (as many as 18 metering apparatus may be installed on the same board, which is generally located in the ground floor of the building).

In case of installation on a central board the functions of the electronic unit are concentrated in one unit (UEPC), performing these functions for all the apparatus of the board.
The photoemitter and the photoreceiver for generation and detection of the optical signals and the final relay for tripping the circuit breaker are the only components inside UEPR, which is therefore a unit having a very low cost.
As a consequence the overall cost of application of the automation system, when the measuring apparatus are installed on a central board, is much less than in the case of single installations.

Fig. 12 shows how either a UEP or a UEPR can be inserted into the back side of a GMY and how the GMY can be installed over a central board.
Fig. 13 shows a central board with one UEPC at the service of all the metering apparatus of the board.

6.2.3 Large LV customers and MV customers

The following Integrated Metering Apparatus have been developed:

- GTWD for LV customers with subscribed demand from 15 to 30 kW (direct connection);
- GTWS for LV customers with subscribed demand from 30 to 250 kW (current transformers are needed on the connection in this case);
- GTWM for MV customers (current and voltage transformers are needed on the connection in this case);

These apparatus are shown in Figs. 14, 15 and 16 respectively; their cases, though differing in some details, are obtained by the same mold.

The current transformers required for the apparatus GTWS are the same in all its field of utilization, from 30 to 250 KW; they are housed in the case shown in Fig. 17, over which the apparatus is installed through a plug-in connection.
As regards the voltage and current transformers required for the apparatus GTWM, only one voltage ratio and three current ratios are used to cover all the field of utilization of the apparatus on the Enel's MV networks with nominal voltages in the range 10 kV - 20kV.
The current and voltage transformers are installed in two different types of housing: the first is an air insulated compartment, the second is an SF6 box (Fig. 18).
The air insulated compartment includes also the coupling device for the transmission of the high frequency signals from the electronic unit to the MV network, while in the SF6 insulated compartment the same device is plug-in over the box (as it is over the MV/LV transformer in Enel's substations), to allow for easier replacement in case of fault.
For the MV customers, we use three current transformers, instead of the two strictly required, to permit the detection of faults, while as regards detection of faults on voltage transformers, this is made by comparison of the peak values of the two measured voltages.
For the same reason, in the case of large LV users with a subscribed power greater than 30 kW, we use four current transformers instead of three.
In case of fault on a measurement transformer an alarm is immediately sent to the center via the electronic unit.

The electronic units used within these apparatus are:

- UEPB for both GTWD and GTWS;
- UEPM for GTWM.

Because no Enel's circuit breaker is present on the user's connection in these cases, these electronic units have the possibility of sending a tripping signal towards the customer circuit breaker, in emergency cases.

7. PRESENT AND FUTURE DEVELOPMENTS

At the end of the year 1990 ENEL has made commands for the following parts of the Distribution Automation System.

The MV network remote control systems (STM) for 6 Zones, corresponding to large urban areas; these systems are expected to become operative during the year 1992.

The customer meter service automation system for all the users (approximately 70 000 users) located in the territory of an Agency in Rome; this system is expected to become operative during the year 1993. This development is aimed at a complete appraisal of all the benefits and problems deriving from the application of the new system in a well defined unit of our organization.

Moreover ENEL has made the following commands of the new types of meters and associated electronic units, to follow the new governmental provisions asking for the application of multirate tariffs to other categories of users:
- 12 000 GTWM and UEPM in the field of the MV users;
- 70 000 GTWS, GTWD and UEPB, in the field of large LV users;
- 30 000 GMY, GTY, UEP (or alternatevly UEPR and UEPC) in the field of LV domestic and commercial users.

These meters will be used in the beginning without the apparatus ACP and ACS in the HV/MV and MV/LV substations; even in these conditions they will allow not only the application of multirate tariffs, but also the automatic reading and command from a remote point of the same network by a portable apparatus. In any case the installation of the ACP apparatus in the HV/MV substations can be envisaged in a few years, while the installation of the ACS apparatus in the MV/LV substations will take a longer time.

In the next years we can envisage the utilization of the new types of meters and associated electronic units, at least to cover the normal needs of replacement, in the field of MV and large LV users, while in the field of residential and small commercial users the same is likely to become reality only if, to ENEL's commitment to progress in this direction, the Manufacturers of the electronic units will be able to answer with a sufficiently low level of prices.
In the longer term a sufficiently low level of prices can reasonably be forecast, taking into account the pace of technological progress in this field.
By starting now these initiatives, we also hope to be able to contribute to the accelaration of this progress.

8. CONCLUSIONS

The Distribution Automation System, described in the paper, offers a comprehensive solution to the automation of the whole set of the on-line activities related to electricity distribution.
Its design has been based on a broad systematic approach that, within a single framework, has covered all the aspects, including the power apparatus, the processing resources at central and remote levels and telecommunications, in order to reach the maximum advantages in term of economy, efficiency and reliability.

BIBLIOGRAPHY

{1} A. Arrigoni et alii "ENEL approach to computer supervisory remote control of electric power distribution network" CIRED 1981

{2} E. Coppa et alii "Metering and control apparatus for MV consumers" CIRED 1983

{3} L. Garzenini et alii "New technologies applied at ENEL for energy metering and consumption data reading" STRASBOURG 1990

{4} E. Comellini et alii "ENEL standardised telecontrol system for MV distribution network automation" CIRED 1989

{5} R. Gargiuli et alii "An experimental prototype of a numeric energy metering unit for L.V. customers" MATES 1990

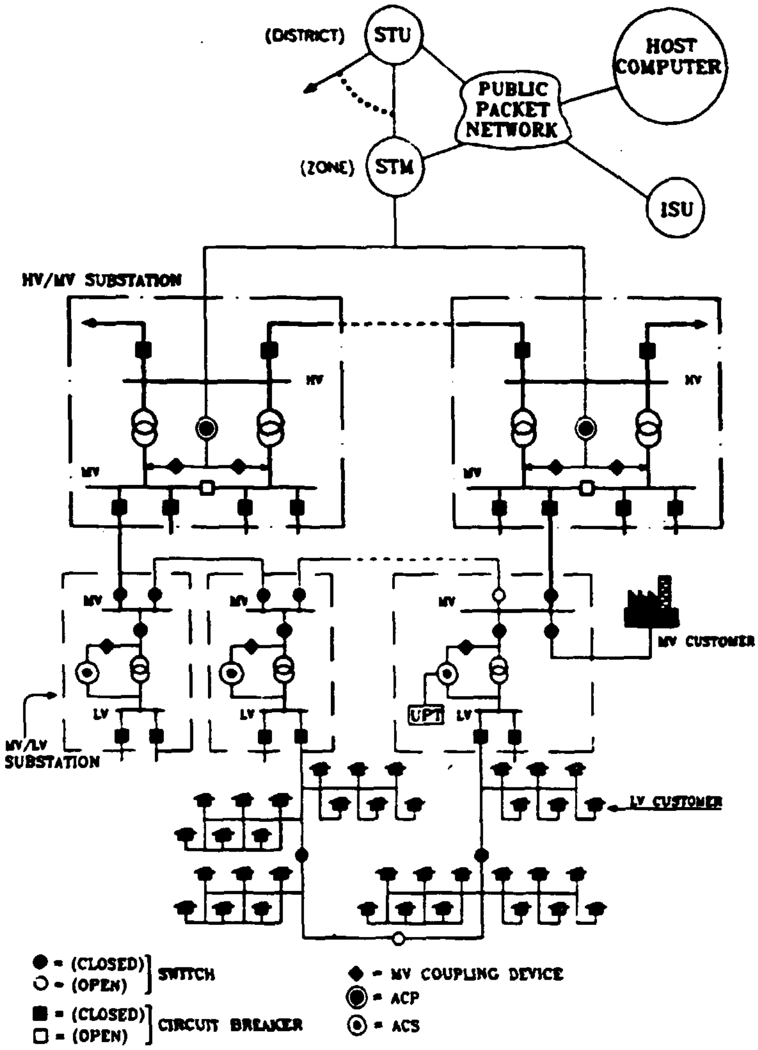


FIG. 1 - ARCHITECTURE OF THE DISTRIBUTION AUTOMATION SYSTEM

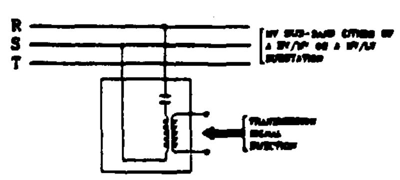


FIG. 2 - DIAGRAM OF THE MV COUPLING DEVICE

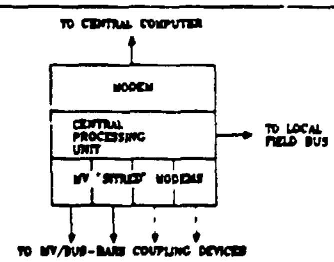


FIG. 3 - SCHEME OF THE ACP APPARATUS

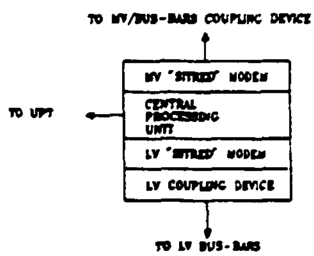


FIG. 4 - SCHEME OF THE ACS APPARATUS

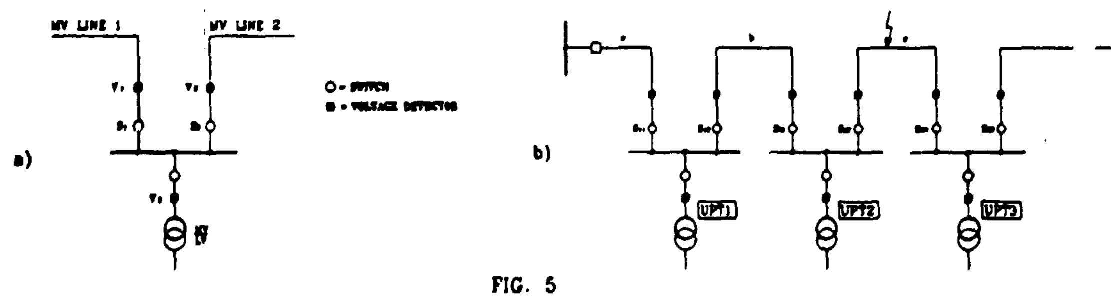


FIG. 5

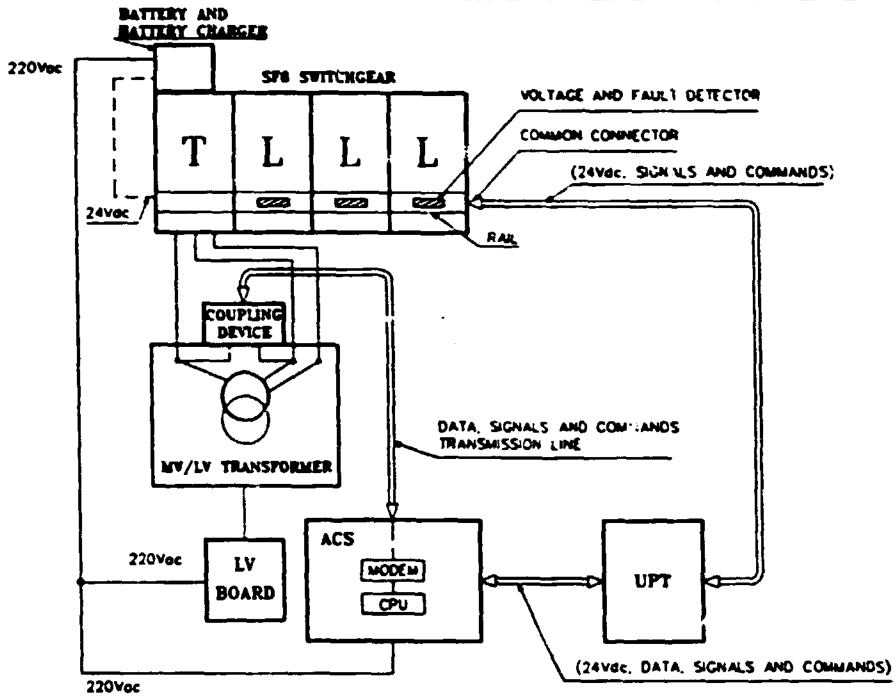


FIG. 6 - TELECONTROLLED MV/LV SUBSTATION

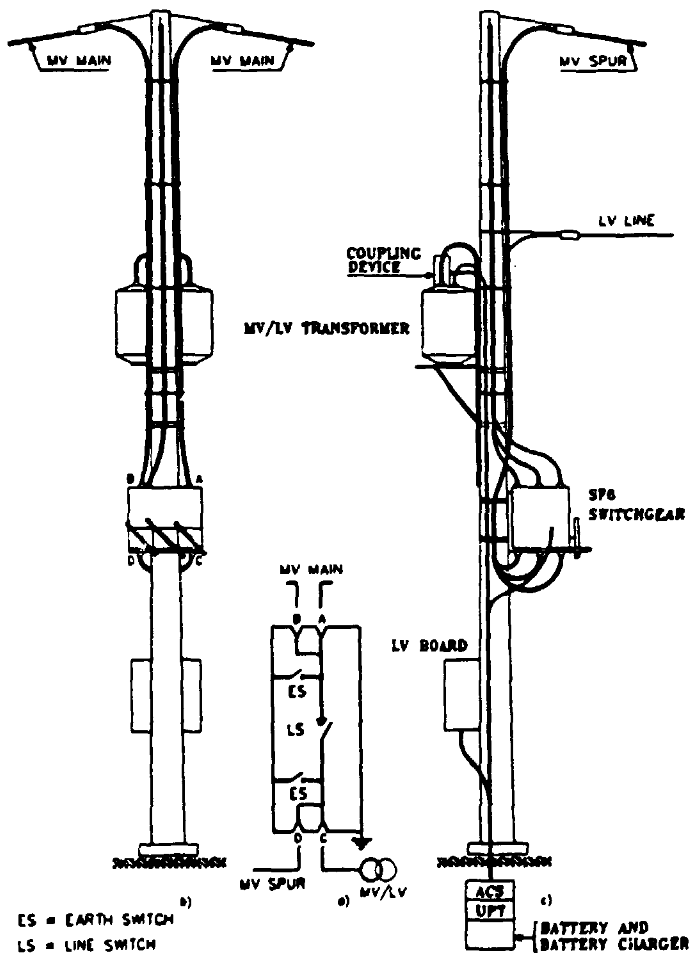


FIG. 7 - POLE MOUNTED TELECONTROLLED SWITCHGEAR

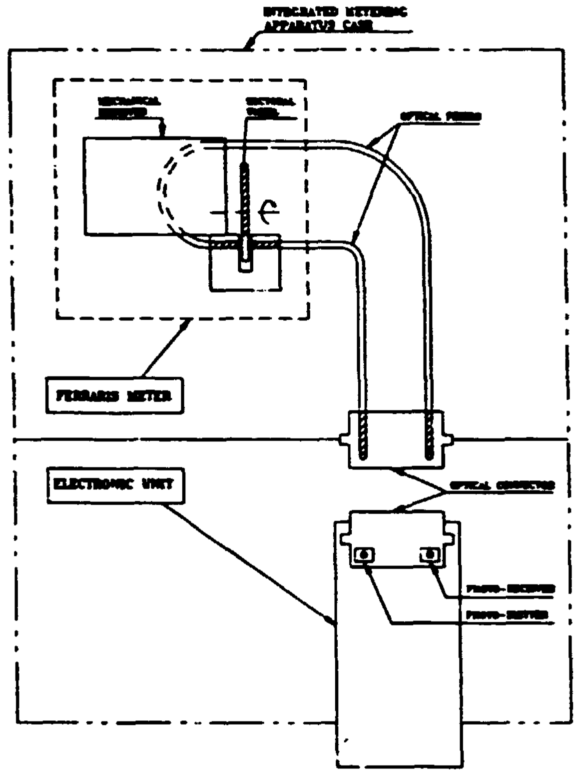


FIG. 8 - METERING PULSE DEVICE

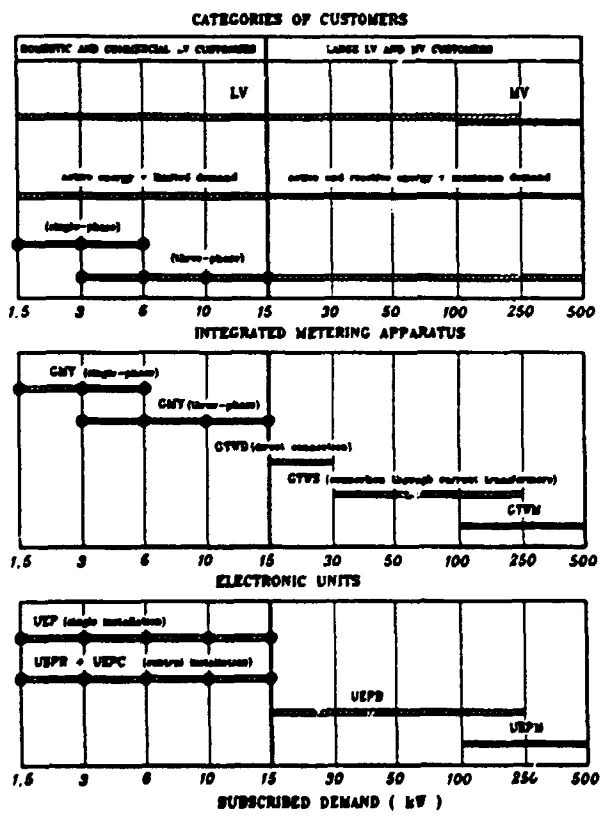


FIG. 9

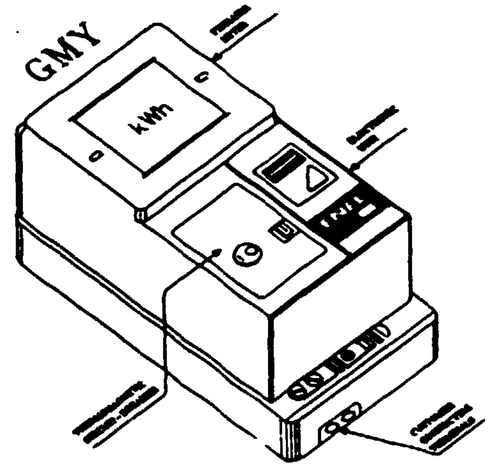


FIG. 10

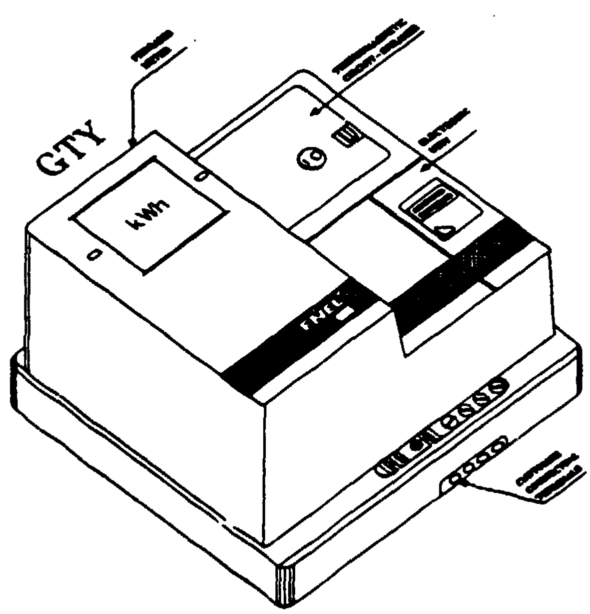
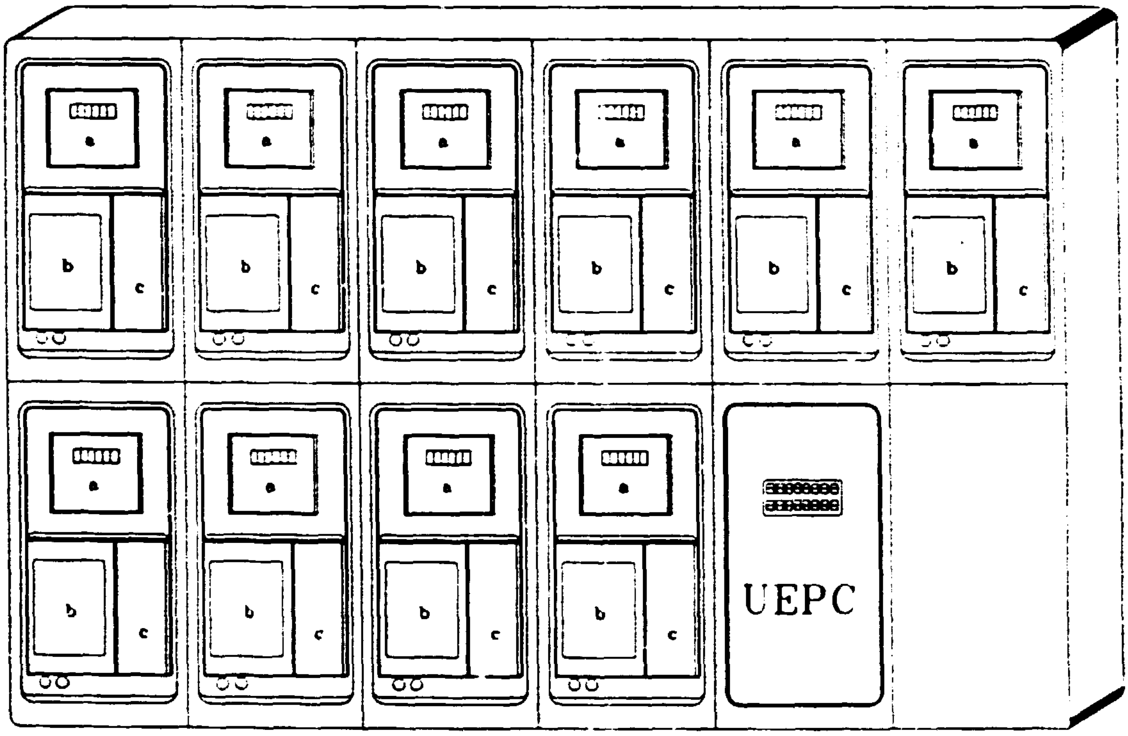


FIG. 11



a = FERRARIS METER
b = THERMOMAGNETIC CIRCUIT-BREAKER
c = "UEPR" ELECTRONIC UNIT

FIG. 13

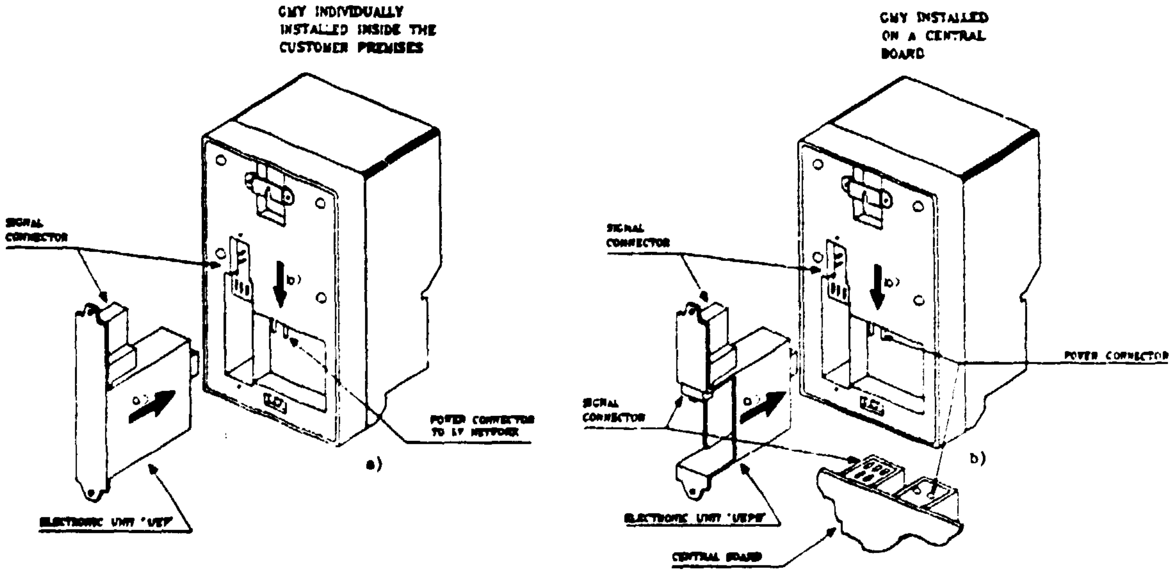


FIG. 12- INSERTION SCHEMES OF:

a) THE ELECTRONIC UNIT UEP INTO THE GMY CASE

b) THE ELECTRONIC UNIT UEPR INTO THE GMY CASE AND THE COMPLEX OVER THE CENTRAL BOARD

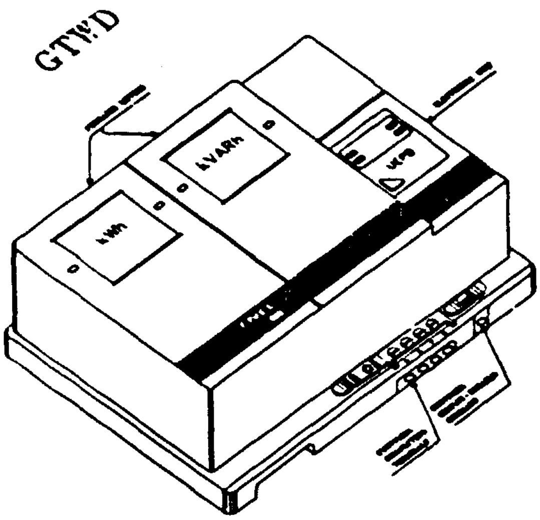


FIG. 14

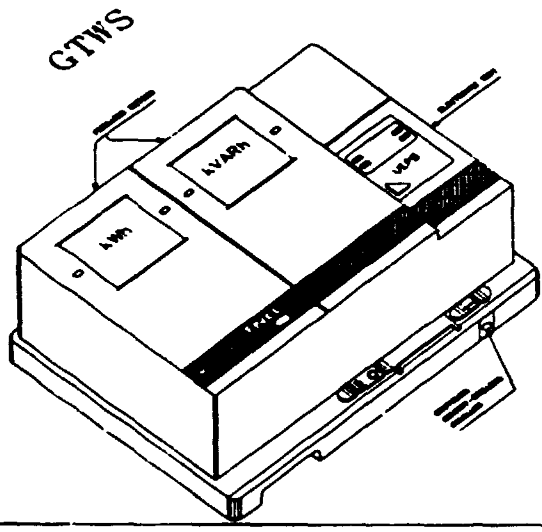


FIG. 15

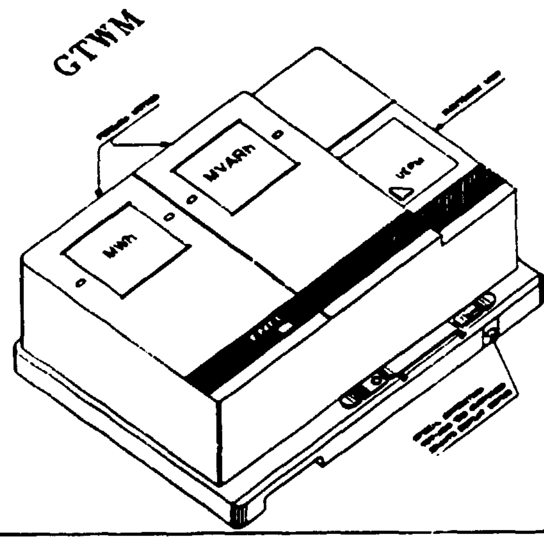


FIG. 16

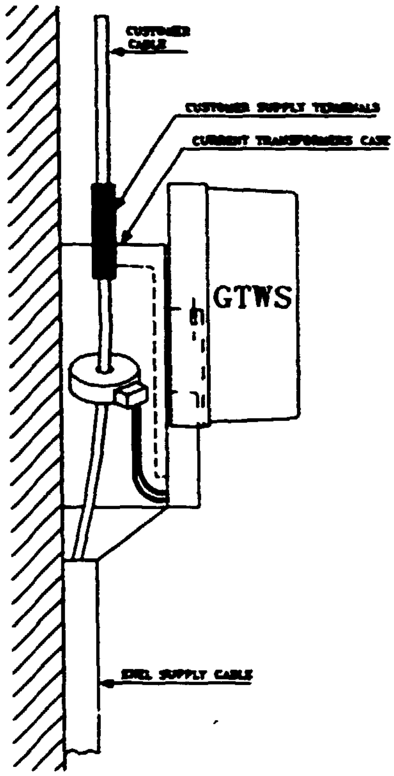

CUSTOMER CABLE
CUSTOMER SUPPLY TERMINALS
CURRENT TRANSFORMERS CASE
GTWS
ENEL SUPPLY CABLE

FIG. 17

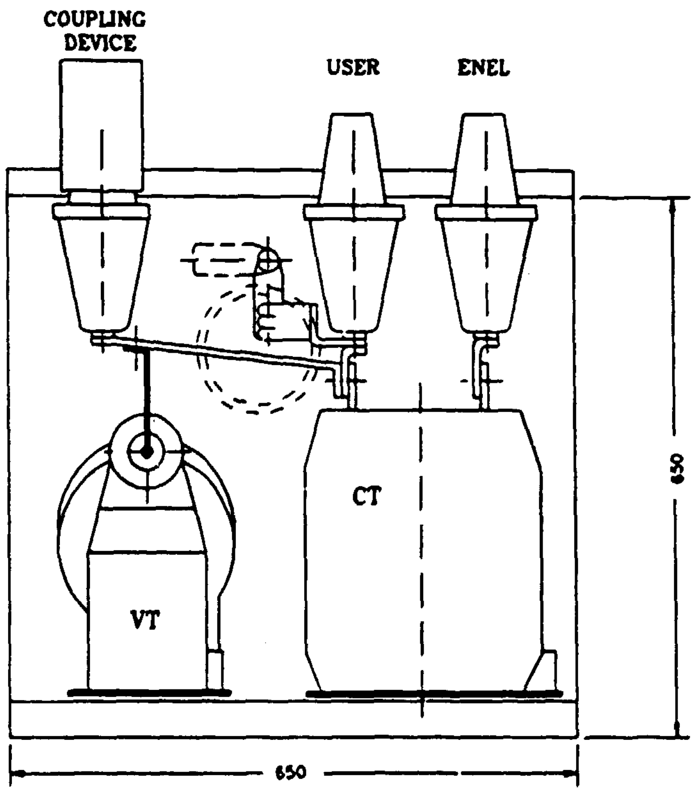

COUPLING DEVICE
USER
ENEL
CT
VT
650
650

FIG. 18