FUTURE CONCEPTS FOR MEDIUM VOLTAGE DISTRIBUTION NETWORKS: A NEW PHILOSOPHY.

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SUMMARY

Both technology and market driven changes take place in electricity networks. This may result in a new philosophy for the future MV network. After summarizing the present situation in the Netherlands,the boundary conditions and some possible concepts for the future MV distribution network are discussed.
It is shown that the availability of electricity can be much improved by applying the new philosophy for new RMU's, without high extra costs.
Finally a concrete project to regulate the voltage level is adressed.

INTRODUCTION

The quality of the electricity supply has always been a point of major interest in the Netherlands. Also worldwide there is an increasing concern about Power Quality [1,2].

Social developments tend more and more to lean towards an increasing dependance on a high quality electricity supply.
Quality means, apart from availabilty, also the amplitude and harmonic content of the voltage.
Developments on the electricity market lead to more competition, reduced costs, accountability for non delivered kW's and kWh's, less maintenance, better customer orientation and satisfaction etc.
Therefore it is a challenge to improve even more the quality, but at minimal extra costs.
In this paper some alternative solutions for the lay-out of the MV network are discussed.
Because the authors foresee that superconductivity will be restricted to "cables" and perhaps fault current limiters in the future, this item is not taken into account.
This paper is based on the near future, i.e. within 10 to 20 years.

TODAYS LAYOUT OF MEDIUM VOLTAGE NETWORKS IN THE NETHERLANDS

The distribution network is principally ringshaped, and operated radially (in open rings). This creates a n-1 redundancy in the structure, but not in the operation mode.
At the beginning of the open ring, a circuit-breaker is placed in the feeding substation.
In the Netherlands 95% of the MV networks are 10 kV and cables are completely laid underground.
A cable fault in such a system leads to an interruption of the supply which can only be restored after a number of (manual) switching operations.
The voltage level is adjusted by tapchangers on the HV-to-MV transformers.
It appears that faults in the MV (3-20 kV)network are the cause of more than 75% of the approx. 20 annual outage minutes for an average LV customer in the Netherlands; 85% of these MV faults are created by cable / sleeve / connection faults. On an average, an LV customer in the Netherlands is once per 5 years without electricity supply, due to MV-faults [3,4].
In figure 1, the situation in the MV network in the Netherlands (like in most other countries) is shown.

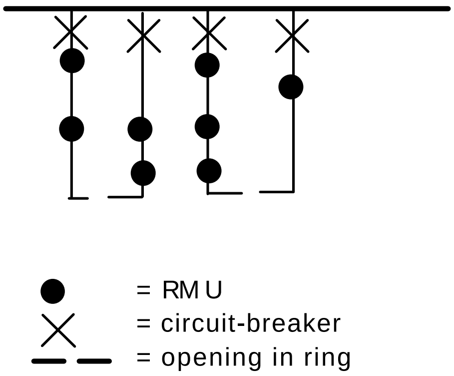

fig.1: Situation of the MV network in the Netherlands

TRENDS AND BOUNDARY CONDITIONS

There are several processes that are already important, or will be soon, for the discussion about tomorrows networks. The total world of electricity is changing and nobody has a blueprint of the future.

From a market driven point of view

Electricity has proven to be an easy and efficient way of distributing energy to the consumer.

Although energy consumption will be at higher efficiency levels in the future, the amount of domestic appliances using electrical energy is growing steadily. So the amount of electricity in the total demand of energy will grow as a method for energy transportation. This results in an average yearly increase in the use of electrical energy of about 2% in the industrialised world.

Privatisation will eventually result in:

- more economical ways of thinking
- reduction of labour costs
- a more critical look towards investments
- electricity changing from a right to a product.

Liberalisation will eventually result in:

- less vertical integration between the stages in the production column of generation, transport and distribution, but a horizontal integration.
- No cross subsidies between the parts of the column or between customers (urban customers are not subsidised by rural clients)
- larger distribution companies with more customer care, splitting up activities for the control of the grid and for selling power through this grid.
- A more rational decision process: cost reduction will become more important.
- Economical managers will decide on investments instead of today's technicians, so economical criteria like depreciation, maintenance and replacement costs will become more important than technical specifications.
- The tasks for the distribution companies will change and grow and there will be a customer oriented differentiation, for example with different levels of availability of power, tariffs and service. Taking care of lighting is a few steps more than just providing an electricity connection.
- There will be a bigger need for information about the energy consumption. This means other and more educated staff, task-oriented business operators instead of process oriented equipment operators. Normal operation activities will however be done by less skilled (meaning less expensive) operators due to the neccessary cost reduction, which is essential during the total lifecycle of the equipment.
- The liability of the distribution companies will be increased, so the insurance of their risks will be more important too. Already today a customer can claim damages from the company, for example when the contents of his freezer has been ruined by a power failure.
- Less time will be spent on maintenance, the applied equipment is expected to be maintenance free with a very high degree of reliability.

Environmental issues:

A reduction in overall power losses leading to the use of less fossile fuel must be achieved.

The influence of the environmental discussions will grow, leading to the fact that the next generation of switchgear must contain environmental friendly materials and it must also be recollected and dismantled at the end of it's lifetime in a safe way by the manufacturer.

A “clean and green” type of power will be demanded in future. This trend is shown on industrial level (triggered by legislation on the maximum amount of CO_2 in the atmosphere) and in the consumer area where influences of environmental organisations are important.

Internationalisation:

In the old days, electricity generation was a local affair; supply was located in the vicinity of the place of consumption. As markets in general become more global, so does the electricity market. Nowadays most countries still have national specifications for the equipment in their grid. International competition and import and export of electricity also result in an exchange of ideas, which will eventually converge.

The government:

In the earliest days of electricity the government saw electricity generation, supply and distribution as its natural task, because electricity offers the opportunity to raise revenue without taxing. The electricity grid will become a production factor instead of a collective property. The role of the government will become more and more a regulator instead of a manager of the market.

According to the government the customer will be free to choose his energy supplier. The role of the government will be reduced to protection of the weak, so nobody will have lack of power and the regulation of labour situations and safety around the distribution of electricity.

Generation:

The days of large electricity power plants seem to be over. Most of the countries have surplus capacity, in former years built to fulfil the peak demand. Nowadays there is more international exchange of electricity, reducing the necessity to have peak capacity available. Reduction of the relative importance of large power plants means that smaller generators will become more important. Smaller generators, which might be privately owned, and linked to the distribution systems in a decentralised manner.

This will make the medium voltage network change from a top-down oriented distribution grid to a general

distribution and transportation grid where the power flow will be less predictable.
Long term planning (and investments) will become less certain and more subject to change. More complex supply management, more flexible planning of the grid structure and development of demand side management will become essential. Overall it can be concluded that the electricity generators and distributors have to become more flexible. Just like a market driven company.

This results in the following policy regarding supply and demand of electricity:

- The production, import and export of electrical power will be free as well as the supply to independent users.
- Expansion of large scaled power generation will be out of order, the existing capacity combined with (inter)national exchange of energy and the use of dispersed energy (combined heat & power generation, wind- and solar power), will take care of future demands.
- In the year 2020 at least 10% of the total demand must be covered by renewable “green” power.
- Between 2020 and 2050 the amount of durable energy must be increased, because of the reduction of CO_2 in the atmosphere and the vulnerability of the Netherlands when depending on the use of only natural gas for power generation.

The points mentioned above mean from a technical point of view:
- increasing load of the electricity grid.
- wide spread use of dispersed generation.
- automatic voltage control.
- the shape of the sine of the voltage is influenced by modern household electronics (harmonic distortions from switched mode power supplies).
- introduction of simple, economical vacuum circuit-breakers that are maintenance free.
- optimisation of load flow.
- low maintenance, even better, maintenance free.
- compact design, but not too compact (you still must be able to handle it properly).
- green and clean (easy handling at end of life) design.
- simple and safe operation.
- Steadily reducing costs for intelligence, sensors and communication.
- Possibility to modify a concept to fulfil the actual specifications needed.

CONCEPTS FOR TOMORROWS NETWORK

A **first** logical assumption is to replace the relatively bulky, and expensive HV fuse by a circuit-breaker (CB) to protect the transformer. This has, amongst other things, the following advantages:[5,6]
- losses reduced to about 5% compared to that of a fuse
- No limitation in current ratings
- Interruption of all possible currents, including those characteristic to evolving faults.
- Possibility to be fitted with protection systems, which are independant of external power, with close discrimination with the LV fuses
- Suitability for remote restoration of the network

A possible drawback of CB’s compared to fuses, is that there is no (peak)current limitation. This seems to be not a point of real concern, since the larger transformers (above 1000 kVA) are always protected by CB’s.
Of course, also the costs involved are a very important factor. Comparison should be made between the total life cycle costs, plus the costs resulting from non availability of the network.

A **second** option is to interconnect the complete MV network, the meshed lay-out. This option seems logical, considering the trends already mentioned. Consequences:

- better loadflow, so less losses; however it is necessary to supervise the loadflow in the network. Also the possible increase of short circuit currents must be considered.
- reduction of impact of dispersed energy, no dependancy on yes or no contribution of the local generator on voltage levels
- better voltage control
- To keep the availability as before, at least 1 circuit-breaker (CB) is needed in the ring at the place of the former opening.
  - directional protection relays are needed
  - By applying even more (selective) CB’s in the ring a large decrease of non-availability can be achieved. In the ultimate case, each RMU is equipped with CB’s so complete n-1 redundancy is achieved for the MV cable circuits. This means for the Netherlands that from the 20 annual outage minutes nowadays, only approx. 7 outage minutes would remain.
  - When every RMU is equipped with CB’s even a reduced lay-out of the RMU is possible (see further on). This might be done for costsavings.

Thirdly, a solution to increase the power quality is to provide the MV/LV transformer with intelligent, automatic tap changing. This intelligent transformer results in an even better voltage control for the end customer in the LV network, see hereafter.

The second and third options are worked out below.

Meshed layout MV network:

Having chosen for a complete interconnection with circuit-breakers in all RMU’s (see fig 2), it is more economical to leave out some components, to end up with the layout, presented in fig 3 or even 4.

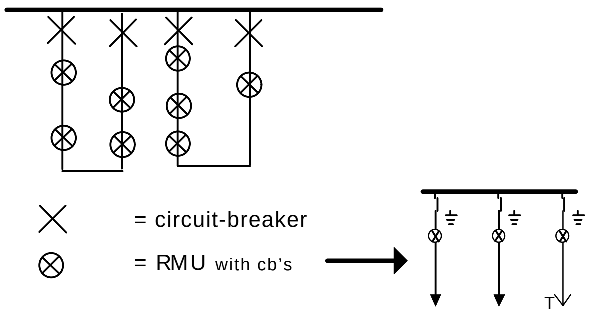

Fig. 2: All RMU's provided with circuit-breakers

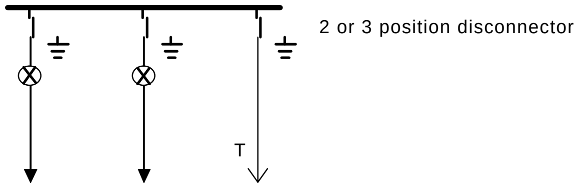

fig. 3: T-off without interrupter

In fig 3 a RMU is shown with no circuit-breaker in the (MV-to-LV) transformer panel.
The main protection at the LV-side takes care of LV faults. Other faults at the T-off side are cleared by tripping both CB's in the RMU.

Cableside faults in the MV grid are cleared by tripping both adjacent CB's, in their respective RMU.

Advantages of the layout in fig 3 compared to the standard RMU (fig 1):

- More economical if the costs of a circuit-breaker are lower than that of two (load break)switches.
- High selectivity is possible; only the cable with the fault between two adjacent RMU's must be switched off. No LV customer will lose its power in such a situation. For the Netherlands this means that the outage minutes and the number of interruptions can be reduced by approx. 75% compared with todays situation.

Disadvantages of the layout in fig 3 compared with the standard RMU (fig 1):

- Attention is needed for energisation from the LV-side; It may not always be possible to have a disconnecting possibility at the LV-side.
- Protection consists of directional overcurrent relays with communication possibilities. At the moment the price of these devices is too high.

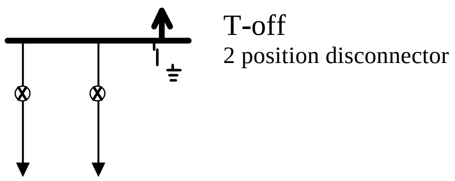

fig. 4: RMU with 1 earthing device

For the sake of costs, in fig 4 there is a further reduction in components created, compared with the layout in fig 3. Only 1 disconnector/earthing device is provided for the complete RMU.
The transformer will be connected directly to the busbar, that is fitted with a conus for cable connection

Advantages of the layout, shown in fig 4:

- low cost for primary parts
- compact design is possible
- clear procedure for earthing

Disadvantages of the layout, shown in fig 4:

- To earth a cable, one complete RMU has to be de-energised for a short period, which will be noticed by LV customers, except for when interconnections have been made in the LV grid. As soon as a take-over earthing is placed in the respective bay (at the cable-side), the RMU can be energised again.
- Transformer faults result in outage of the complete RMU, until the connection has been removed, and a proper termination at the RMU is made.
- With cable testing on an energised RMU, an increased dielectric stress appears across the circuit-breaker CB, except when the busbar of the RMU is de-energised.

The drawbacks that are mentioned above, are that in principal, the layout, as shown in fig 4, may be considered to be not realistic.

Intelligent transformers

The increased awareness of customers with respect to Power Quality means that distribution companies need tools to ensure that the voltage supplied at the delivery point complies with the agreed specifications.
Traditionally the amplitude of the voltage was ensured by choosing impedances of distribution systems so that the voltage in the worst-case points would not be outside the tolerance band. If required, high to medium voltage transformers would be equipped with on-line tap changers in order to reduce the tolerance on the medium voltage.

The consequences of distributed generation in the low voltage networks is that the power direction is undefined and more variation of the amplitude of the LV is possible. Lowering the impedance of the supply system, by choosing a different transformer, adding an extra line/cable or changing the circuit layout, is a logical way to cope with this problem. The associated increase in short-circuit power however initiates a cascade of measures to ensure that the system can deal with higher short-circuit levels. At the end of the day the costs are significant.

Another way to reduce the effect of voltage variations is to provide the MV to LV transformer with an on line tap changer, controlled by the amplitude on its LV side or at a specific distant location in the LV system. The cost of such equipment is considerable, but moreover a mechanical switch introduces a significant maintenance requirement. See fig 5.

A much more elegant way to solve this problem is to use an electronic variant of such a tap changer. By using state of the art power electronics, it is possible to create a continuously variable output voltage using only two taps. In fig 6 the scheme of the electronic options is given.

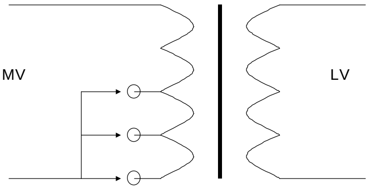

Fig. 5: Single-phase equivalent of an MV to LV transformer using a mechanical tap changer.

In fig 5, the three taps could represent for instance +5%, 0, -5% of the nominal voltage.

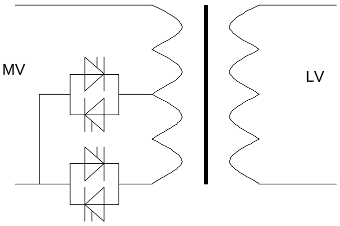

Fig. 6: Same transformer as in Figure 5, but with electronic voltage control.

Using only two electronic switches and Pulse Width Modulation the transformer ratio is continuously variable between e.g. +5% and -5% of the nominal value.

The electronic version has numerous advantages over a mechanically switched variant:

- Voltage is continuously variable instead of stepwise.
- Electronic control permits the use of additional "intelligence" for optimal voltage control.
- The electronic version can always be operated instantaneously.
- Because many electric variables of the transformer are measured by the control system, a connection to a SCADA or EMS system is straightforward and offers a considerable enhancement of the monitoring capabilities of the SCADA system.

An EMS system could also be used to change the setpoint of the transformer from the utility's control room. This offers new options for load management, as experience in ENECO has shown that the amplitude of the low voltage can be used to manipulate the instantaneous power demand.

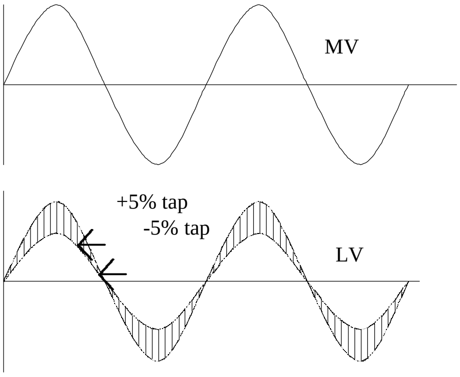

Fig. 7: PWM switching principle.

The principle of PWM is explained in figure 7 above. The upper trace represents the MV waveform, the lower trace represents the secondary waveform. The dotted lines (envelope at LV) are the voltage levels corresponding to the two taps on the MV winding; the rectangular waveform results from alternating between these two taps. The effective LV amplitude will be a weighted average of the two dotted lines.

The two electronic switches are opened and closed alternately. The repetition rate of opening and closing depends on the capabilities of the semiconductors used. Distribution transformers up to 1 MVA with a control range of ±10% would be equipped with IGBTs operating at a switching rate in the order of 10 kHz. The same principle can be applied to higher rated power transformers in which the electronic switches would be based on IGCTs with a switching rate of several kHz. In all events the frequency would be high enough to be effectively damped by the inductances in the supply system.

A transformer operating according to this principle was built by the Technical University of Delft, the Netherlands, under a contract from ENECO. The concept is patented in the Netherlands and patents in other countries have been applied for. The photograph in fig. 8 shows the prototype. Field test units are planned to be delivered by SMIT Transformers later this year.

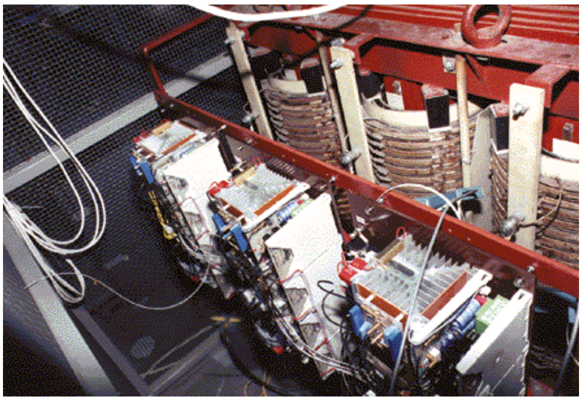

Fig. 8: Laboratory prototype of electronically controlled transformer

CONCLUSIONS:

Market driven changes will result in higher power quality demands, against no or minimal extra lifetime costs of the equipment.
The growth in applying dispersed energy will continue.

High power quality demands may lead to a meshed MV grid.
This can be price-worthy in the near future, because:

- the prices of protection and communication devices, related to their functionality, continue to decrease.
- A reduced layout of the RMU's is acceptable, if the majority of RMU's is equipped with intelligence and communication devices.
- The price of non-availability will increase

Another aspect in increasing the power quality is the application of intelligent transformers, to keep the voltage within a certain bandwith.

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