ECONOMIC ASPECTS OF REACTIVE ENERGY MANAGEMENT IN ROMANIAN MARKET

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Reactive energy management plans covers producers, transporters, distributor and customers. The paper presents aspects of reactive energy management at distributor and customer.
After a short introduction of the main technical aspects of reactive energy (meaning and measurement), the paper presents financial economical flows related to reactive energy at distribution/customer level in Romanian market. Short presentation of other European reactive energy billing systems is presented.

Detailed insight of the Romanian billing system is presented with practical examples. Based on this, an analysis of actual system is made and main hurdles to a coherent reactive management system are named. Instead of conclusion, proposals are made in order to improve the economics behind the reactive management.

Key words: **reactive energy, billing system, network management**

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INTRODUCTION

After 1990, electricity market in Romania changed from monopoly to "so to say" competitive energy market. Figure 1 presents a simplified relationship chart based on actual structure. The market participants are: the producer, the transporter, the distributor, the supplier and the client. On the market energy and services are sold. Figure 2 gives a more detailed view of the contractual relationship between the parties involved in the market.

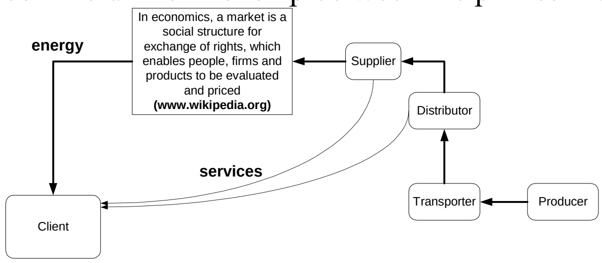


Figure 1 Energy market participants and relations

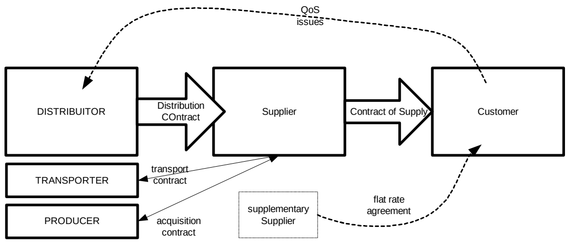


Figure 2 Contracts in the market

Dealing with reactive energy in such a complex system leads to a complex problem. Since the space of this paper is limited, only some of the problems in the market will be covered. Table 1 presents the domains that will be treated by the paper.

Table 1 Coverage of the reactive energy subject in the paper

	reactive energy management plan	reactive energy measurement	reactive energy billing	reactive energy financials
production	X			
transport	X			
distribution	X	X		X
Supply			X	
Customer			X	

Most of the contractual relations presented in figure 2 are obvious:

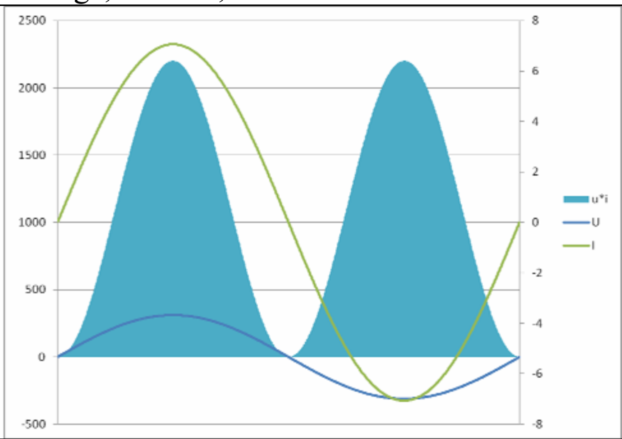
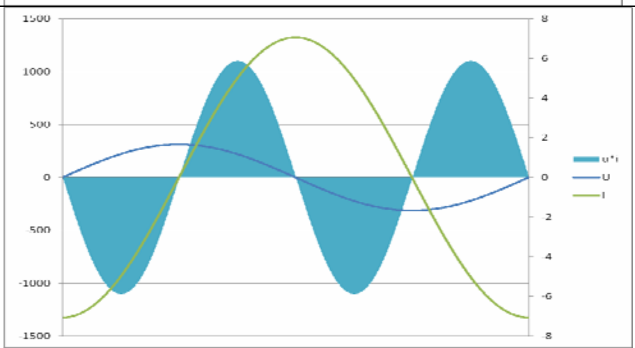
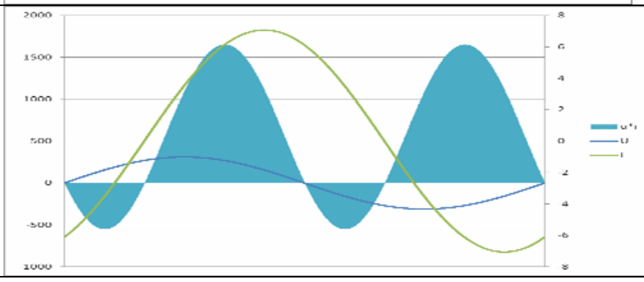
- There is a supply contract between supplier and customer;
- Between distributor and supplier there is a distribution contract;
- The supplier has to sign contracts for the production and for the transport of the energy too.

A special appears when there are two suppliers for one customer. In this case, direct distribution contract between customer and distributor is allowed by the regulation. Among QoS (quality of service) issues between customer and distributor there is the reactive energy problem.

REACTIVE ENERGY

The reactive energy in an alternative current system is defined as the captive electrical energy exchanged continuously between the different electric and magnetic fields associated with the operation of the electrical system [6]. Voltage and current alternate up and down 50 times per second. Because of this, the power being transmitted down a single line also “pulsates” - although it goes up and down 100 times per second as could be seen in the charts in table 2. When there is no phase shift between voltage and current, all the power goes from the producer to the consumer. This is the case of the first row chart in table 2. If we have a quarter period phase shift between current and voltage, the average power transmitted to the load is zero. If this average value is zero, then all of the power being transmitted is called “reactive” power as could be seen in the second row of the table. This is the case of the second row in the table 2. You would not normally be charged for using reactive power because you are consuming some energy half the time, and giving it all back the other half of the time - for a net use of zero [1]. Both cases are ideal. In the real world, there is always a phase shift between current in voltage. As could be seen in the third row of table 2, in the case of a 30˚ phase shift we have both a component of the power going to the load, and a component pulsating between load and source. To distinguish reactive power from real power, we use the reactive power unit called "VAR" - which stands for Volt-Ampere-Reactive.

Table 2 time diagrams of current, voltage and power for different phase shift cases

Case	Voltage, Current, Power chart	Comments
1		Phase shift is zero. Voltage and current are in phase. The load is resistive. All the power is transmited to the load meanning that is active. Power factor equals 1.
2		Phase shift is π/2. Voltage and current are shifted quarter of cycle. The load reactive. The power pulsates between load and source Power factor equals 0.
3		Phase shift is π/6. Voltage and current are shifted one sixth of cycle. The load is both active and reactive. The power pulsates between load and source Power factor equals 0,5.

The reactive energy definition widely accepted today was stated by Constantin Budeanu in the paper "Puisance reactive et fictive" in 1927. This definition is formally expressed by:

$$Q = UI\sin(\phi) = \sqrt{S^2 - P^2} \tag{1}$$

The number of nonlinear loads is continuously increasing. That makes the distribution network, more and more polluted by harmonics. With a distorted regime, Budeanu's definition was extended to harmonics according to the relation:

$$Q = \sum_{n=1}^{\infty} V_n I_n \sin(\phi_n) \tag{2}$$

Applying reactive energy measurement according to equation (2) on a large scale is expensive and difficult. That's why, in electronic meters used for billing different methods of calculation were developed [2]. Among the most popular are: Hilbert transform [3], power triangle [7], time delay [4], filters [5]. We've made an analysis of the reactive energy recordings, for a customer using electronically assisted motors. In table 3 the results of two month measurements are presented. The consumer has two 11kW fixed consumption motors and three 7,5kW motors variable frequency controlled.

Table 3 energy registered by four meters at Calarasi PT 4 Braila

	active energy [kWh]	reactive energy [kVARh]
triangle method meter 1	7924	6042
triangle method meter 2	7922	6038
hilbert transform	7933	2070
electromechanical meter		2120

As could be seen, the meters that use triangle method are registering almost three time more reactive energy. In order to explain this, we continued the investigation. First of all we analysed the load profile for the meters involved. Figure 3 shows the results of measurements made under non sinusoidal conditions for active and reactive power. Then we analysed the voltage and current waves. Relevant for this analysis is current and voltage wave spectrum presented in figure 4.

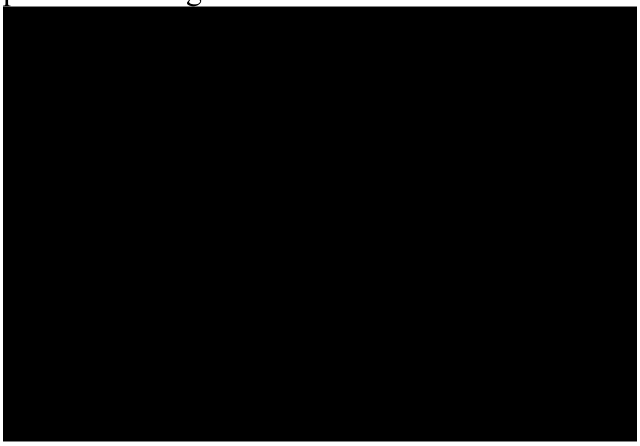


Figure 3 load profile for electronic meters

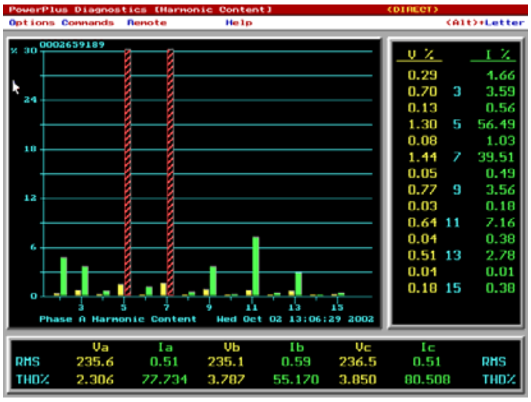


Figure 4 spectral analysis for voltage and current

Doubtful results of reactive measurement leads to less effective management plans. Reactive energy measurement made using electronic meters in non sinusoidal condition depends on the algorithm used by internal software. Main factor of stress is the way meters calculate using distorted current and voltage curves.

Reactive energy money flows

Analysis of the financial flows associated with reactive energy starts with distribution and transport tariff analysis. Figure 5 presents the detailed image of the contract relations in the market as it was presented in figure 2. Supplementary information regarding tariff coverage is added to the chart. For instance, both tariffs covers cost of: maintenance investments and losses. When it comes to the losses there are multiple categories of costs covered by the tariff: commercial losses, meter tampering, technical losses. A further split of the technical losses could get us to the link with the reactive energy. Since technical losses management is base on a model that takes into account: line losses, transformer losses, phase shift losses among others that means the information regarding the influence of reactive energy on the energy is covered through the distribution tariff. Similar deduction could be obtained for the transport tariff. On short we can say that the distribution and transport tariff includes a fair amount of money for the management of the supplemental losses determined by the reactive energy flow.

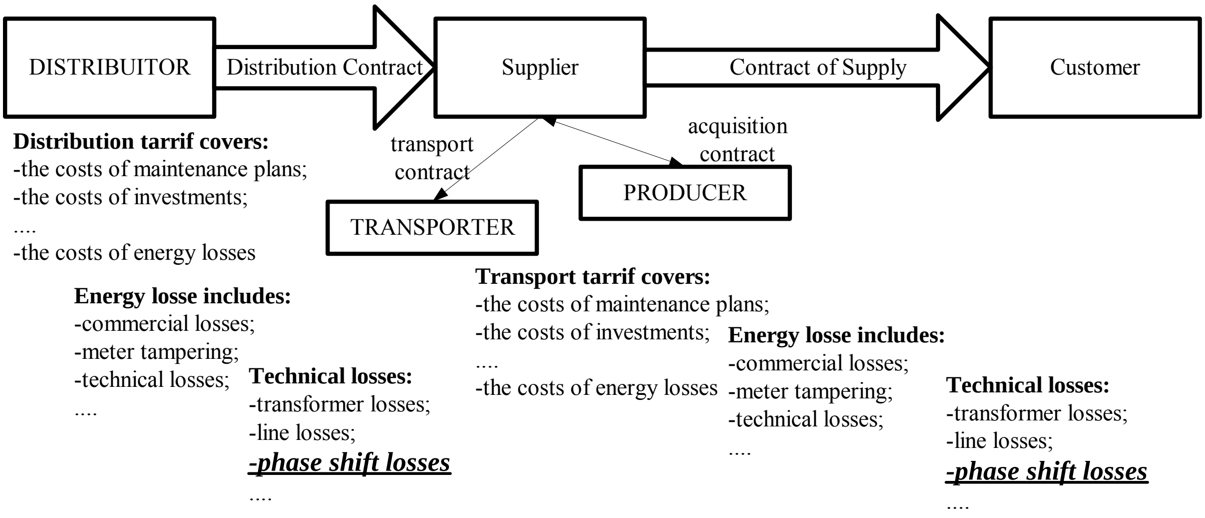


Figure 5 distribution and transport contract coverage

Besides the money got from the customer by the supplier in order to cover the distribution and transport tariffs as shown in figure 5, there is another contribution dedicated to reactive energy. To be more precise, the money are meant to cover the supplemental losses determined by customer's shift of the current referenced to the voltage.

There are three main regulation that give reactive norms in Romania: RED Code [12]; RET code [13] and PE 120. Customers have to respect the limits for reactive consumption established by regulation [12]. Al market participants (transporter, distributor, customer) has to compensate by itself the reactive consumption. In special cases determined by the safety of the system reactive power exchange is accepted [13]. Neutral power factor of the system is periodically established by studies [14]. Figure 6 presents the money flow related to reactive energy bill.

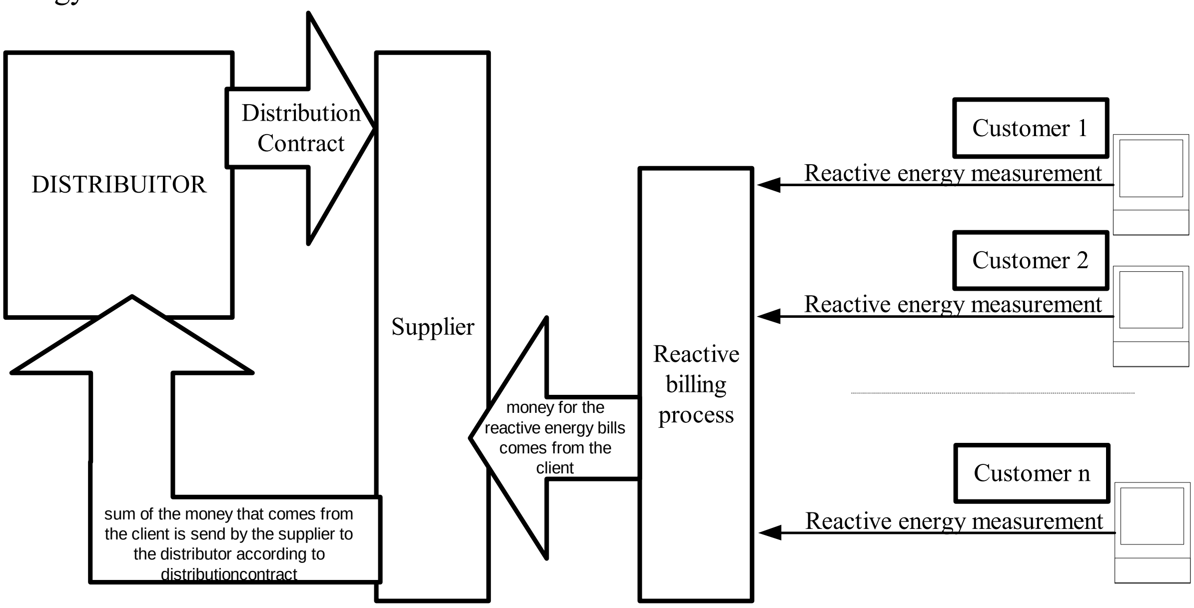


Figure 6 reactive energy money flows

As could be seen in the figure, this amount of money is based on metering equipment results. From the meter readings reactive energy values are processed and a reactive energy bill is made. The bill is payed by the customer, and the money collected to the supplier goes to the distributor. Figure 7 shows the billing rules for reactive energy in the Romanian market. After reading the meter, both inductive and capacitive energies are calculated. The capacitive energy is billed as it is. The rate for reactive energy is more or less one tenth of the active energy rate. For the inductive energy, there is a system parameter called neutral power factor that is compared to the power factor for the billing cycle. According to energy regulator, this factor is 0,92. If the power factor is better than 0,92 then no reactive energy is billed. If power factor is lower than 0,92 then another test is made. The power factor is compared to 0,68. If the power factor is between 0,92 and 0,68 the bill is made similar to capacitive case. If the power factor is lower than 0,68 then all the reactive energy is payed at a triple rate.

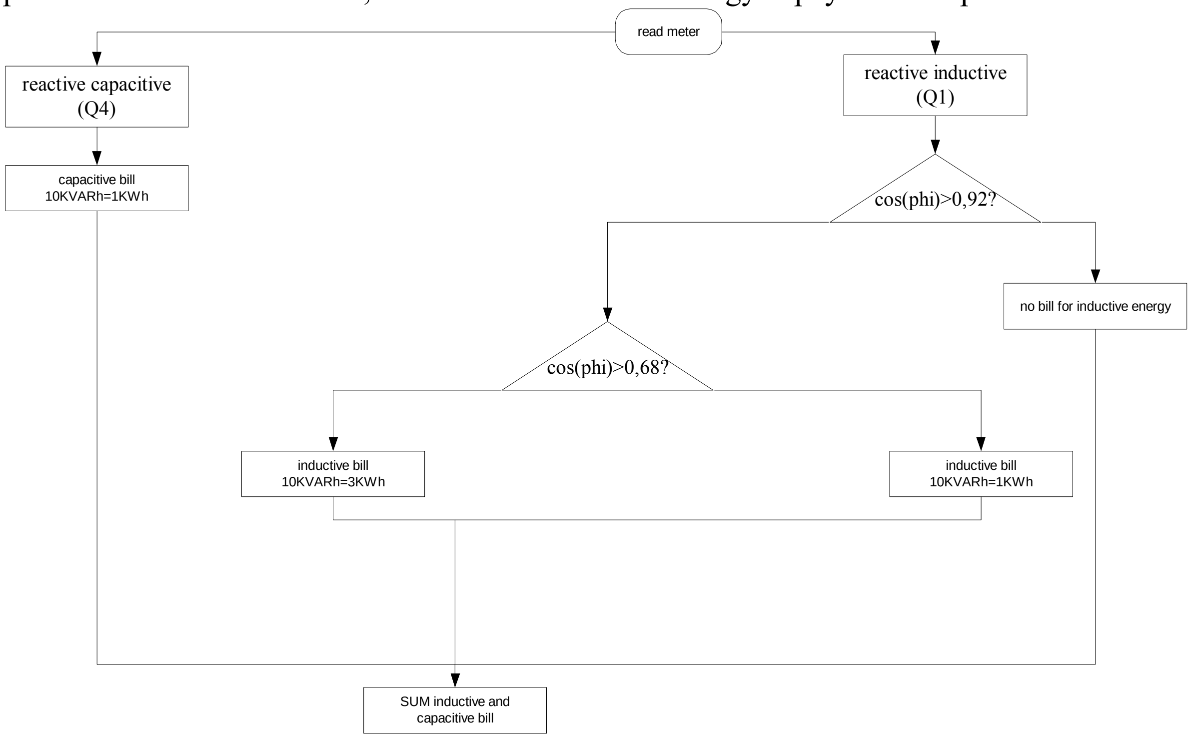


Figure 7 reactive energy billing process

This billing system, should bring a powerful tool for reactive energy control and management for distributors. The problem is that putting the control mechanism at the border between distributor and client doesn't produce the results expected. Normally this system should be extended to all management levels in the network.

Other money/reactive compensation mechanisms

Table 4 shows several mechanisms used to compensate economically the reactive energy consequences.

Table 4 Reactive energy compensation

nb.	Country	Commecial reactive?	TSO/DSO-DNO	Distributed generation	Commercial customer	Residential
1	Austria	yes	DSO and TSO take care for a sufficient extent of reactive power on his own (additional agreements with generators), TSO provides balancing.		Reactive power is metered separately. If Business-Customers use more than 50 % reactive power in relation to active power (cos(φ) >0,9) the use exceeding will be billed. This revenues shall cover only the expenses of the grid operator related to reactive power.	Houshold-Customers do not have to pay for the use of reactive power.

nb.	Country	Commecial reactive?	TSO/DSO-DNO	Distributed generation	Commercial customer	Residential
2	Slovak Republic	no, only penalities	On the side of TSO, in the supply points TSO - DSO, the excessive inductive reactive power is compensated in coils connected to the terciar winding (10,5 or 22 kV) of VHV/HV transformers.	Customers (HV, MV and wholesale LV customers, not households, nor small firms) as well as distributed generators must have **power factor (cos Phi) from 0,95 to 1 inductive** (lagging power factor). If they do not comply with this requirement, there is a penalty to the price of electricity according to the price list approved by regulator. For the customers that have four quadrant meters also over-compensation is checked and penalised.		
3	Spain	Reactive power is billed	Distribution: peak hours: cos(φ)> 0.95; night hours: cos(φ)< 1; off-peak hours (except night hours): 0.95< cos(φ)< 1Transmission: according to the TSO orders.		This regulation sets the penalties for end consumers in case of non-compliance with a cos (φ)> 0.95.	
4	Portugal	reduction of demand for reactive power is set up in the tariff of access to the grids	DNO proceeds to the compensation in HV/MV substations. During peak period in excess (inductive) of 40% of active power is invoiced. Monthly values for active and reactive power are taken into account for this invoicingThe reactive power supplied to the network (capacitive) during off-peak hours (night and week end) is invoiced	The active power supplied to the grid has to be accompanied by reactive power in the amount of 40% of the active power. The reactive power in deficit is invoiced	reactive power should be compensated at consumer level as transmission of reactive power leads to an increase in thermal losses, a decrease in supply voltage and a need for network reinforcement.	For customers at low voltage with a subscribed demand less than 41,4kVA there is no explicit invoice of reactive power. In fact, these customers are paying apparent total demand (in kVA and not in kW) as they have a demand control by a circuit breake
5	US	yes	Most of US utilities, bill according to maximum reactive demand [11]. For these utilities, the reactive power charge is proportional to the amount by which the customer's maximum reactive power demand exceeds a threshold. The level of the threshold varies substantially among utilities, with values ranging between 10% and 62% of peak real power demand, and with an average value around 50% of real power demand, equivalent to an 0,89 power factor.			
6	Luxembourg	yes	In Luxembourg, similar system based on power factor is used [8]. If power factor is lower to 0,8944 the customer is subject to a penalty. This penalty could vary between 6 and 15 Euros per kVArh and is added to distribution costs.			
7	Peru	yes			Luz del Sur, a private, electric power distribution company that provides service to more than 700.000 clients in the southeast area of Lima, capital of Peru, bills reactive energy if it exceeds 30% of the total active energy consumed during the month. Only excess will be billed [9].	

Getting to power system level, the power factor requirements vary [10] from 0.85 (UK and Wales) for generated to 0.98 (Norway) for absorbed reactive power. Annual volume of reactive power market in Lithuania could reach 5.2 million Euros. Total costs of reactive power in Lithuanian power system are obtained by summing all reactive costs of generators, synchronous condensers and static compensators. In Austria, generators have to feed more than 50 % reactive power in relation to active power into the grid (cos (φ) < 0,9). Exeption: due to reasons of power quality at the connection point DSO can set differing requirements if necessary. In Spain generation has to respect cos (φ) = 0.989 for both in-take/off-take reactive power. In New Zealand, reactive power sources and costs of transmission and control of reactive power limited to the Auckland region [11]. System operator has a few long-term supply contracts with generators that allow such additional voltage support to be specifically requested under certain circumstances. The pricing of this additional supply depends upon the source, and for generators usually includes the opportunity cost of foregone real power sales. ISO's payments under these contracts form part of the cost of purchasing voltage support ancillary services.

PROBLEMS OF REACTIVE ENERGY MANAGEMENT SYSTEM

There are six categories of interested parties involved in reactive energy management: the energy producer; the transporter, the distributor, the supplier, the customer and the regulator. Any reactive management plan should follow a Deming loop like the one presented in figure 8. Steps to a successful reactive management are: planning the reactive management; applying the plan; checking the results; acting according to the results in order to improve the efficiency of the loop. The options with the fourth step are: to recheck the results of the measurement; to check the actions and their results and in the end to adjust the plan.

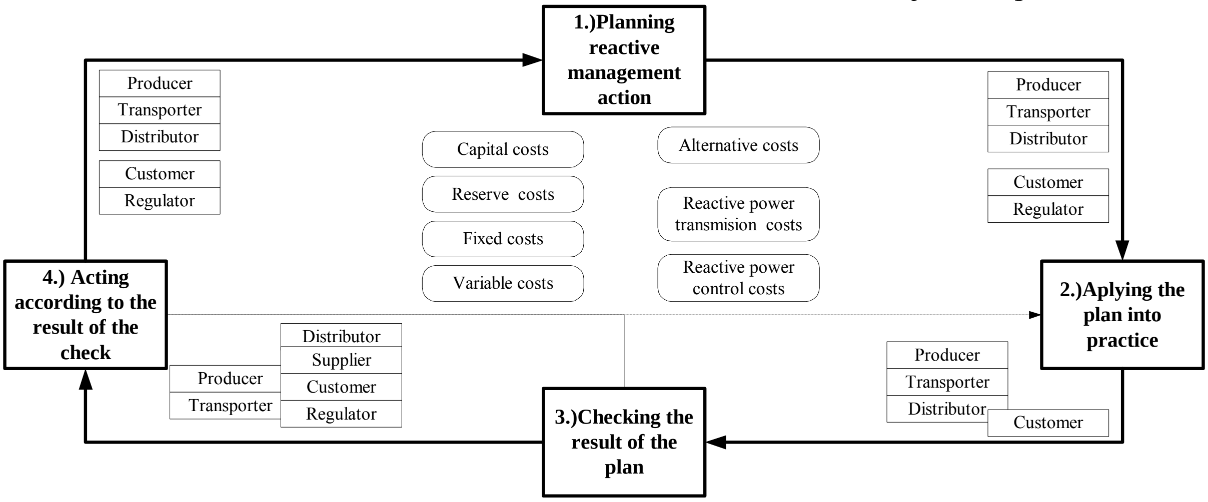


Figure 8 general Deming management loop applied to reactive energy management

The responsibilities of the parties involved in the reactive energy management are different. One of the factors that make the difference between the participants is the cost associated with the reactive energy management. Seven cost categories were identified: capital costs, reserve costs, fixed costs, variable costs alternative costs, reactive power transmission costs and reactive power control costs.

Most of the reactive energy management plans are made at system level and does not take into account the details of reducing reactive energy consumption at source.

CONCLUSION

Metering method used for reactive energy measurement should be presented to the beneficiary in order to avoid mistakes in defining reactive management plans. Mistakes could be generate by the confusion between reactive and deformant energy.

Since there is different parameter values used for reactive energy management, a common model is necessary in order to get to comparable practical results.

Reactive energy pricing should cover both fixed and variable costs. That's why more transparency is needed in building these costs and splitting them into distribution tariff and direct bill

Reactive power market is based on a monopsony – the only buyer is the system administrator. Building a reactive power market for variable cost could lead to a more efficient price mechanism if the value of the reactive source takes into account the "distance" to the consumption.

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