

Reactive Power Management and Regional Reactive Load Forecast in Turkish Electricity Energy Market

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Abstract—In deregulated power systems, isolated system operators are responsible for providing the limits of active power flow and bus voltages on transmission lines. Reactive power management has very significant role for isolated system operators because of not only operating the power system safely and bus voltages and transmission line loadings in limit values, but also minimizing costs of the system. The aim is to emphasize the significance of reactive power in electricity market. In this study at first reactive power issue is generally approached, and then economic and technical issues of reactive power procurement are stated. Reactive power pricing and some boundaries are also explained for Turkish electricity market. At the end of this study, reactive load is forecasted for 2011-2015 years in European Land of Istanbul through least mean squares method. In coming four years reactive power compensation for that region will have been resolved.

Index Terms—Reactive power pricing, electricity market, reactive power management, load forecast.

I. INTRODUCTION

While electricity energy necessity is increasing all over the world, to parallel this situation, the necessity of uninterrupted energy supply to consumers occurs. In large electricity energy systems, sometimes it is not to be able to control bus voltage levels causing significant voltage collapses over the grid. Inadequate reactive power is one of the most important reasons of these collapses such as occurred in Sweden and Denmark in 2003 [1]. Reactive power has a significant role for maintaining the voltages at transmission lines in required limits and increasing power transfer capability of the system [2]. The magnitude of reactive power and its effects on system stability are very important while system works hardly [3].

In order to supply reactive power necessity of the electrical grid, power plants produce reactive power and also compensation facilities satisfy this necessity. Generators, synchronous condensers, fixed and shunt switchable capacitors, fixed serial capacitors and Static VAR Compensators are the reactive power sources. Transportation of reactive power is also difficult. While heavily loading of the system, reactive power losses occur more than active power losses, in addition to this; reactive power consumption and losses increase significantly over long transmission lines [1]. Due to these situations, reactive power should be procured near of the demand.

Many of countries limit the reactive power consumption and procurement from/to the system, regulate power transfer

values between reactive power suppliers and grid and in case of being exceeded of the limits, and apply penal sanctions to the related corporations. A new term named “reactive power management” has come up over the world due to increasingly significance of reactive power and as a result of this a new market has occurred in electricity markets. Energy Market Regulatory Authority (EMRA) regulates reactive power issues like active power through making technical regulations in Turkish electricity market.

This paper aims at explaining the reactive power limits that are related to production and consumption and pricing mechanism in Turkish electricity market. In Section II, some economical and technical issues; in Section III, reactive power pricing and limits are approached. In Section IV, regional reactive load is forecasted for Istanbul. Section V is the conclusion of this paper.

II. ECONOMIC AND TECHNICAL ISSUES OF REACTIVE POWER PROCUREMENT

As mentioned in Section I, reactive power may be supplied with different sources. These sources have some priorities to each others. According to the demand and location, one of the sources may be chosen. While choosing the best source, economic properties are also very important.

Economic costs of reactive power include explicit and implicit costs. These costs also include generation and transmission costs. Explicit costs are capital costs of the facilities and operational costs of the production that must be paid directly. The capacity used to produce reactive power is a big part of the explicit costs of generation costs. Maintenance costs are small operational costs. Implicit costs of the generation are related to capacity restrictions of the generators named loading capacity diagram. Explicit costs of the transmission sources are the costs of reactive compensators and tap-changing transformers. Total cost (TC) of the reactive power support may be calculated through Eq. 1 [4].

$$TC = \sum_g C_g \cdot \Delta Q_g + \sum_c C_c \cdot \Delta Q_c + \sum_t C_t \cdot \Delta Tap_t + C_L \Delta P_L \quad (1)$$

where C defines cost, Δ defines change, Q_g defines the reactive power output of the generators, Q_c defines reactive power output of the compensators, Tap_t defines the ratio of the tap-changing transformers and P_L defines the lost active power on transmission lines. To minimize this total cost, each cost must be minimized as much as possible

$$\begin{aligned} \text{Cost of generators} & \sum_g C_g \cdot \Delta Q_g, \\ \text{Cost of compensators} & \sum_c C_c \cdot \Delta Q_c, \\ \text{Cost of transformers} & \sum_t C_t \cdot \Delta Tap_t, \\ \text{Cost of losses} & C_L \Delta P_L \end{aligned}$$

In order to produce reactive power by generators, less active power and fuel is needed. Generators are equipped with automatic voltage regulators that control reactive power output via regulating excitation. There is a maximum limit to produce reactive power by generators, if this limit is exceeded; generators lose the control of the voltage. Shunt capacitors are used to compensate reactive power losses and maintain required voltage levels on transmission lines. Serial capacitors are linked to line conductors to decrease inductive reactance of the line. SVCs have many aspects affecting the performance of the transmission system such as controlling temporary over voltages and inhibiting voltage collapses due

to having the capability of controlling reactive power and voltage [2].

In Turkish electricity market, reactive power producer must regulate the voltage of the bus connected to production facility at a value and within a certain tolerance adjusted by regional load distribution center and/or system operator through reactive power capacity at each unit of production facilities. Producer may fulfill these liabilities in two different ways that are controlling via an outer loop and an operator shown in Fig.1 and Fig. 2 [5].

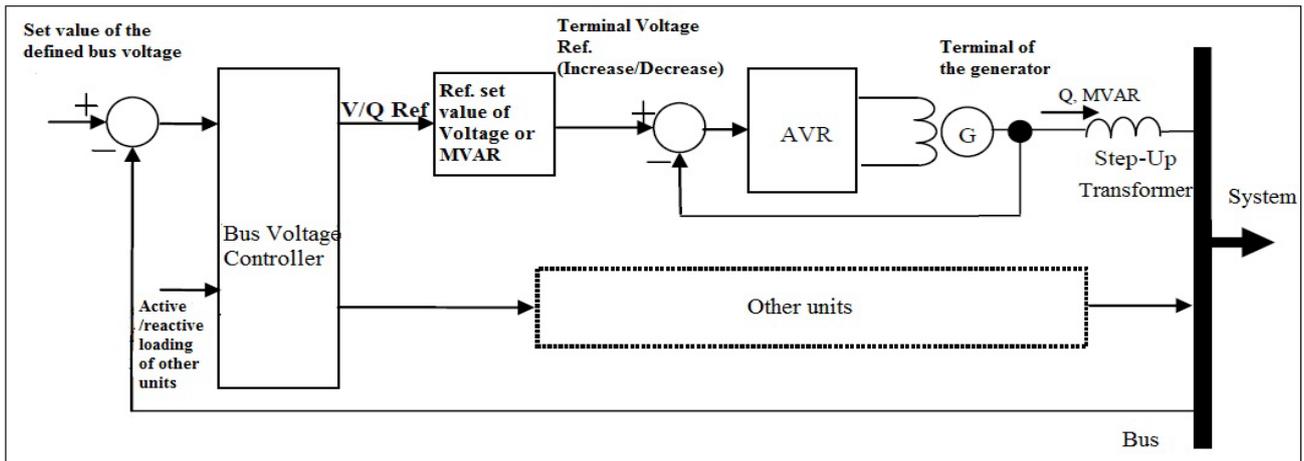


Fig. 1. Control via an outer loop

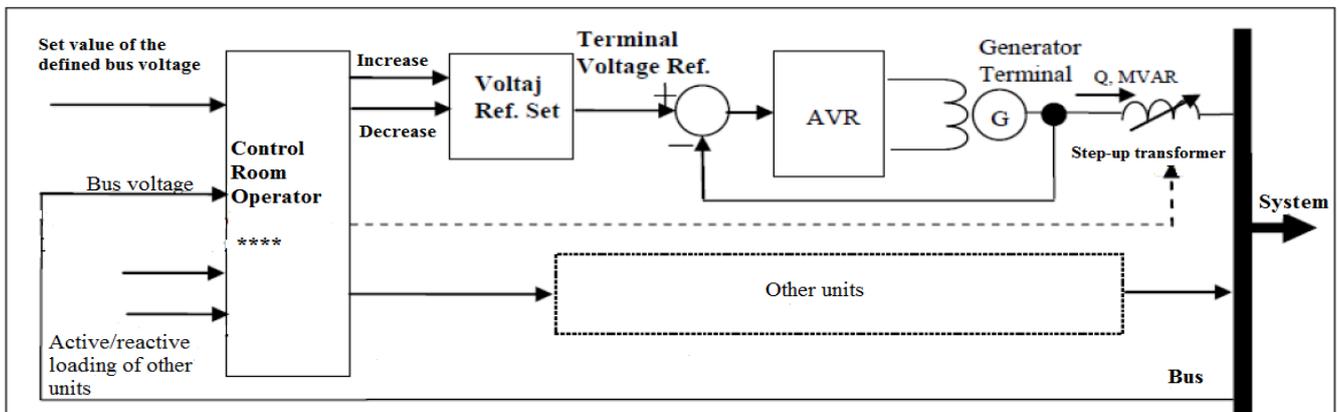


Fig. 2. Control via an operator

In order to determine reactive compensation system data, user presents below data for reactive compensation facilities on the system:

- 1) The output of the reactive compensation system is constant or variable
- 2) Operation ranges for capacitive and/or inductive regions of reactive compensation systems
- 3) Tap-changing settings of reactive power outputs
- 4) Automatic control features and settings of reactive power output
- 5) Connection point of the reactive compensation system to the system of the user [6].

III. REACTIVE POWER PRICING AND LIMITS IN TURKISH ELECTRICITY MARKET

For regular pricing mechanism, active and reactive power sources should absolutely be defined. If reactive power prices are less than available value, no one wants to procure reactive power and the sources are adjusted to generate only active power. Due to the cheap price of reactive power, consumers will increase their demands. This situation causes voltage collapses due to having inadequate reactive power of the system. If reactive power prices are more than available values, consumers will decrease their demands due to the expensive price. In order to prevent these situations, reactive power mechanism should be adjusted correctly.

In Turkish electricity market, synchronous compensation amount which is paid to the legal personality having production facilities for synchronous compensator is calculated in Eq.2.

$$SKA_{p,t} = \sum_{f=1}^m [\sum_{h=1}^m (SIP_{t,h} + AEECA_{p,f,t,h}) + SCSP_{p,f,t}] \quad (2)$$

where $SKA_{p,t}$; credit balance (Turkish Lira, TL) which will be accrued due to operating as synchronous compensator at term t of production facilities belong to legal personality having p production facilities,

$SIP_{t,h}$; System Imbalance Price (TL/MWh that is valid for “h” hour at t term,

$AEECA_{p,f,t,h}$; Active Electricity Energy Consumption Amount (MWh) in h hour at t term of f production facility belongs to legal personality operates p production,

$SCSP_{p,f,t}$; Synchronous Compensation Service Price (TL) that is valid for t term of f production facility belongs to legal personality operates p production,

k ; number of production facilities belong to legal personality operates p production,

m ; number of hours for t term define.

Except this price, EMRA and other corporations related to electricity market point some rules about exceeding the boundaries which determined by that corporations. In the Table I, reactive power limits may be seen.

TABLE I: REACTIVE POWER LIMITS FOR DIFFERENT CASES IN TURKISH ELECTRICITY MARKET

Case	Limits (Power Factor)	
	Inductive	Capacitive
Distribution		
Ins. power < 50kVA	0,95	0,98
Ins. power ≥ 50 kVA	0,98	0,989
Transmission	0,98	0,989
Production		
Prod. fac. units	0,85	0,95
Syn. compensator		1
Thermal units	0,66	0,95
Hyd.elec.units	0,66	0,8
Wind power plant	0,85	0,95
Retail Sales		
Con. power > 9 kW	0,95	0,98
Compensation fac.	0,95	0,98

For retail sales, home users and users having less than 9 kW connection power are exempt for paying reactive power price. If the consumption exceeds one (ind. or cap.) of these cases, user must pay whole reactive power consumption price. When exceeding both cases, users must pay more one.

For transmission systems, when user exceeds the limit must pay 50% of system usage price as penalty once a month. If any fault occurs on compensation facilities, in case of not exceeding more than one in a year, user should not be punished. If this situation repeats, user must pay 50% of system usage price as penalty once a month for each case [8].

IV. REACTIVE LOAD FORECASTING FOR EUROPEAN LAND OF ISTANBUL

Istanbul is one of the important cities over the world with approximately 15 million people. European Land of Istanbul has almost 9 million people and most of industrial facilities are also in this region. Bosphorus Electrical Distribution Company gives electrical services and is responsible for applying the rules. In recent years, due to the significance of reactive power compensation issue, this company has built new compensation facilities; but these are not enough to compensate exactly. In this section, it will be shown that through using the reactive energy consumption values from the substations of past five years, the required installed reactive power compensation facilities for 2011-2015 years is calculated. Least mean squares method is used and in case of the power factor is 1, required installed power is shown. Forecast is done at 84 substations of 31 different locations.

1) Linear Method

$$y = ax + b \quad (3)$$

In Eq.3, “y” is the desired value; “a” is the slope and “b” is the cutting point of “y” axis. While using linear least square methods,

$$\begin{aligned} (\sum_{i=1}^n x_i^2)a + (\sum_{i=1}^n x_i)b &= \sum_{i=1}^n x_i y_i \\ (\sum_{i=1}^n x_i)a + nb &= \sum_{i=1}^n y_i \end{aligned} \quad (4)$$

$$\begin{aligned} a &= [n(\sum_{i=1}^n x_i y_i) - (\sum_{i=1}^n x_i)(\sum_{i=1}^n y_i)] / [n(\sum_{i=1}^n x_i^2) - (\sum_{i=1}^n x_i)^2] \\ b &= [\sum_{i=1}^n y_i - a(\sum_{i=1}^n x_i)] / n \end{aligned} \quad (5)$$

Simultaneously solving of above equations (4, 5), a and b values can be calculated. y defines the reactive energy consumption values, x defines years and n defines number of years.

2) Exponential Method

$$y = ab^x \quad (6)$$

In this equation, simultaneously solving of above equations (7,8), “a” and “b” values can be calculated. “y” defines the reactive energy consumption values, “x” defines years and “n” defines number of years.

$$\text{Log} y = \text{log} a + x \text{log} b \quad (7)$$

$$a = (\sum_{i=1}^n \text{log} y_i) / n - (\sum_{i=1}^n x_i) b \quad (8)$$

$$b = \left[n \left(\sum_{i=1}^n x_i \text{log} y_i \right) - \sum_{i=1}^n \text{log} y_i \sum_{i=1}^n x_i \right] / \left[n \sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i \right)^2 \right]$$

3) Quadratic Method

$$y = a + bx + cx^2 \quad (9)$$

In Eq.9, simultaneously solving of Eq. 9 and Eq.10, “a”, “b” and “c” values can be calculated. “y” defines the reactive energy consumption values, “x” defines years and “n” defines number of years.

$$an + b \sum_{i=1}^n x_i + c \sum_{i=1}^n x_i^2 = \sum_{i=1}^n y_i \quad (10.1)$$

$$a \sum_{i=1}^n x_i + b \sum_{i=1}^n x_i^2 + c \sum_{i=1}^n x_i^3 = \sum_{i=1}^n x_i y_i \quad (10.2)$$

$$a \sum_{i=1}^n x_i^2 + b \sum_{i=1}^n x_i^3 + c \sum_{i=1}^n x_i^4 = \sum_{i=1}^n x_i^2 y_i \quad (10.3)$$

Above three methods are applied to the forecast, the forecasted results are shown in Fig. 3. Except exponential method, the reactive energy consumption values go to “0” in 2014.

When error rates are calculated shown in Fig. 4, linear error rates for past 5 years are most acceptable, because of this required installed power is calculated through this

method for each substations.

European Land of Istanbul has 144 MVar compensation powers, as a result of this forecast at the end of 2014 years while building new 148 MVar compensation power totally shown in Table II, required installed power for compensation will be adequate.

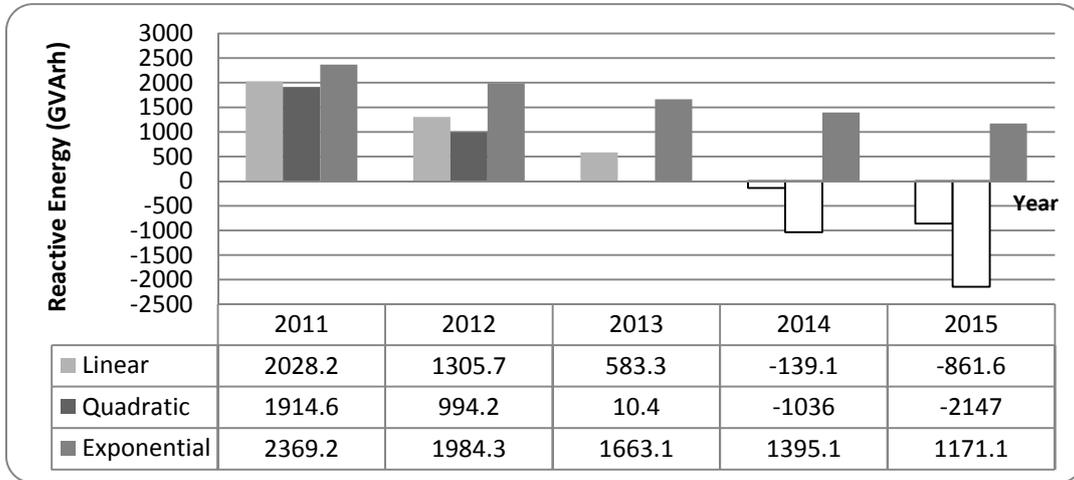


Fig. 3. Forecasted reactive energy values for 2011-2015 years with each method

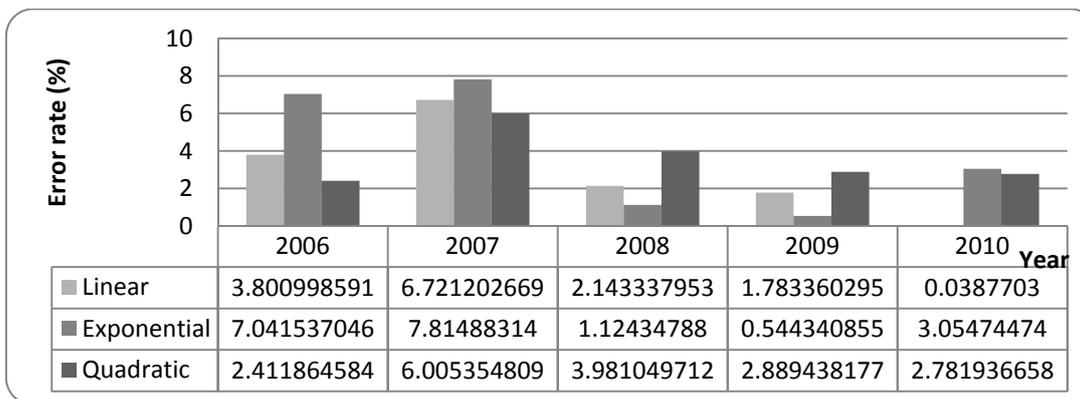


Fig. 4. Error rates for past five year with each method

TABLE II: REQUIRED COMPENSATION POWER

Years	Req. Comp. Power (kVAr)
2011	39000
2012	39000
2013	39000
2014	31000
2015	0
TOTAL	148000

V. CONCLUSION

The significance of reactive power management has been increased due to demand of electricity energy. In this study, reactive power issues for Turkish electricity market are approached and a forecast about reactive power compensation for an important part of Istanbul is done. Through building the shown installed power, this region will finish reactive power necessity.

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Mükail Akbulut was born in Istanbul in 1986. He graduated from Istanbul Technical University Electrical Engineering Department in 2009. Right after he finished Master Thesis at same department. He works for Turkish Airlines Technic Inc. as an Avionics Maintenance Engineer and also studies PhD. at Istanbul Technical University Electrical Engineering Department.



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