A NEW AHP – BASED REACTIVE POWER VALUATION METHOD

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I would like to dedicate this work to:

My beloved wife Margaret Stephen Mozimin, my son Aiden Vinsley and Adler Vance

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ABSTRACT

In Malaysia, the electricity tariff is based on the active energy consumed and does not include any reactive (energy) power required. In order to recover the extra cost incurred in supplying the reactive power required by the consumers, the utility imposes a surcharge on a consumers whose power factor averaged over a month is below the value of 0.85pf. However, the surcharge is imposed on medium to large commercial and industrial consumers only. This paper proposes a new method for valuation of Reactive Power in power system. This method uses two important factors to determine the most important Reactive Power source power system. These two factors are: Voltage Sensitivities and Voltage Adequacy and Stability (PV Curve). In this paper AHP method has been used to classify the Reactive power sources according to their importance in power system. The effectiveness of the proposed method is verified under IEEE 9-bus system.

ABSTRAK

Di Malaysia, tarif elektrik adalah berdasarkan kuasa aktif yang digunakan dan tidak termasuk sebarang kuasa reaktif (tenaga) yang diperlukan. Dalam usaha untuk mendapatkan kembali kos tambahan yang ditanggung dalam membekalkan kuasa reaktif yang diperlukan oleh pengguna, utiliti mengenakan surcaj pada pengguna yang mana penggunaan faktor kuasa purata dalam sebulan adalah di bawah nilai 0.85pf. Walau bagaimanapun, surcaj hanya dikenakan pada kepada pengguna komersil sederhana dan perindustrian yang besar sahaja. Projek ini mencadangkan satu kaedah baru untuk penilaian Kuasa reaktif dalam sistem kuasa. Kaedah ini menggunakan dua faktor penting untuk menentukan Kuasa Reaktif yang paling penting dalam sistem sumber kuasa. Kedua-dua faktor adalah: Sensitiviti Voltan dan Kestabilan serta Kecukupan Voltan (PV Curve). Dalam kes ini, kaedah AHP telah digunakan untuk mengelaskan sumber kuasa reaktif mengikut kepentingan mereka dalam sistem kuasa. Keberkesanan kaedah yang dicadangkan diuji menggunakan sistem IEEE 9-bas.

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LIST OF SYMBOLS AND ABBREVIATIONS

HVDC	-	High Voltage Direct Current
P	-	Power
G	-	Generator
L5	-	Load 5
L7	-	Load 7
L9	-	Load 9
VsG1	-	Voltage Sensitivity generator 1
VsG2	-	Voltage Sensitivity generator 2
VsG2	-	Voltage sensitivity generator 3
$\sum VsGi$	-	Sensitivity of each generator to the marginal change of all loads
$\sum VsLi$	-	Sensitivity of each load to all generators
QLsGi	-	Q losses sensitivities of the generator
QLsLi	-	Active power loss sensitivity to Reactive power changes

CHAPTER 1

INTRODUCTION

1.1 Project background

Power factor is defined as the ratio of real power to apparent power. This definition is often mathematically represented as kW/kVA, where the numerator is the active (real) power and the denominator is the (active+ reactive) or apparent power. Reactive power is simply, when a coil or capacitor is connected to an AC power supply, the coil or capacitor stores electrical energy during one-fourth of an AC cycle. But then during the next quarter-cycle, the coil or capacitor dumps all the stored energy back into the distant AC power supply.

Customers of electricity in Malaysia normally domestic users rarely care about the aspect of reactive power as the cost of reactive power is not included in the bill. Issue that the customer concerns especially industry is more to the voltage stability and efficiency of power system. Efficiency determined by Power Factor, meanwhile reactive power has a big impact on power factor. However, many do not realize (except the industry) that the reactive power is one of the factors that could affect the stability and efficiency of the power system. Equipment such as generators, motors, transformers, air-conditioners, refrigerators, fans, welders and fluorescent lights are partly resistive and partly reactive. For this project generator will be used as the reactive power source. One of the purposes of this project is to determine which the generator among three generators that has most important role in power system.

1.2 Problem statements

Power factor is a measure of the active power required compared with reactive power. The higher the reactive power factor the lower is the power factor. An electrical installation or equipment operating at higher power factor requires less current compared with one with lower power factor. For the same active energy required, an electricity supply system with lower power factor requires a higher current to be generated and supplied through the transmission and distribution system. This will lead to an increase in equipment and cable cost and will result in higher energy loss in the power supply system.

In Malaysia, the electricity tariff is based on the active energy consumed and does not include any reactive (energy) power required. In order to recover the extra cost incurred in supplying the reactive power required by the consumers, the utility imposes a surcharge on a consumers whose power factor averaged over a month is below the value of 0.85. However, the surcharge is imposed on medium to large commercial and industrial consumers only.

Power system networks nowadays are forced to be operated much closer to stability limits due to the increased demand for electric power than ever before. In such a stressed condition, the system may enter into voltage instability problem and it has been found responsible for many system block outs in many countries across the world. Voltage instability is primarily caused by insufficient reactive power support under stressed conditions. A power system needs to be with sufficient reactive reserves to meet the increased reactive power demand under heavily loaded conditions and to avoid voltage instability problems. Reactive reserve of generators can be managed by optimizing reactive power dispatch. Generator bus voltages and transformer tap settings are the control parameters in the optimization of reactive power. The amount of reactive power reserves at the generating stations is a measure of degree of voltage stability.

1.3 Project objectives

The main objectives of this project are as follows:

a) To specify the reactive power sources according to their importance in power system.
b) To compare various options available for a particular objective function, especially in the assessment of Reactive Power evaluation.
c) To determine the generator that has a most important role in power system.

1.4 Project scopes

The scopes of this project are:

a) AHP method is used to compare various options available for a particular objective function, especially in the assessment of Reactive Power evaluation.
b) Two classifications will be use which is Voltage Sensitivities and Voltage Adequacy and Stability (PV Curve Method).
c) Reactive power evaluation is to be done for only three reactive power sources.

CHAPTER 2

LITERATURE REVIEW

2.1 Theories

Explanation for reactive power says that in an alternating current system, when the voltage and current go up and down at the same time, only real power is transmitted and when there is a time shift between voltage and current both active and reactive power are transmitted. But, when the average in time is calculated, the average active power exists causing a net flow of energy from one point to another, whereas average reactive power is zero, irrespective of the network or state of the system. In the case of reactive power, the amount of energy flowing in one direction is equal to the amount of energy flowing in the opposite direction (or different parts -capacitors, inductors, etc. of a network, exchange the reactive power). That means reactive power is neither produced nor consumed.

Payment for reactive power becomes an issue in electric power supply in other countries. In Malaysia the cost of reactive power is not included in payment, as the bill will only for the real power. But it still becomes an issue when discussing about voltage stability or power system efficiency. Reactive power can influence the efficiency of the power system in terms of power factor. Increase in reactive power caused a decrease in power factor. Valuation of reactive power can be classified into several methods which are Voltages Sensitivities, Voltage Adequacy and Stability, Equivalent Reactive Compensation (ERC) and Back-up generation.

Physical analogy said that suppose I want to fill a water tank with water, one bucket at a time. Only way is to climb a ladder, carrying a bucket of water and pouring the water into the tank. Once I fill up the tank, then I have to go down the ladder to get more water. In this one cycle of going up the ladder and coming down I have done some work or the energy required to go up is more than the energy required for coming down. If I had climbed the ladder with an empty bucket, and I had come down with the same bucket I am not doing any work.

The energy for upward and downward motion is the same. Though I have not done any work – worth paying for- I require some energy. That is, the energy that it takes to go up and down a ladder carrying nothing either way requires reactive power, but no real power. The energy that it takes to go up a ladder carrying something and come down without carrying anything requires both real power and reactive power. The analogy can be extended for explaining 3 phase system if we put 3 ladders going up to the tank and 3 people climb up in sequence such that there is always a steady flow. Another analogy, a bit simplistic, is the "*TehTarik* analogy".

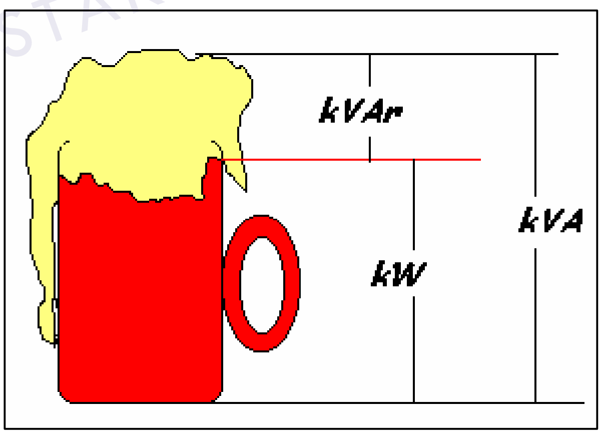

Figure 1.1:*TehTarik* Analogy

Power Factor = Active power/Apparent power = kW/kVA

= Active power/ (Active Power +Reactive Power)

= kW/(kW+kVAr)

= *TehTarik*/(*TehTarik*+Foam)

The more foam (higher kVAr) indicates low power factor and vice versa.

2.2 Reactive power sources

According to Erche. M [3] reactive power is produced or absorbed by all major components of a power system:

1. Generators;
2. Power transfer components;
3. Loads;
4. Reactive power compensation devices.

2.2.1 Generators

Electric power generators are installed to supply active power. According to Kirby [1] additionally a generator is supporting the voltage, producing reactive power when over-excited and absorbing reactive power when under-excited. Reactive power is continuously controllable. The ability of a generator to provide reactive support depends on its real-power production. Figure 2.1 shows the combined limits on real and reactive production for a typical generator.

The different reactive power sources of a power system are synchronous generators and shunt capacitors. During a disturbance or contingency the real power demand does not change considerably but reactive power demand increases dramatically. This is due to increased voltage decay with increasing line losses and reduced reactive power generation from line charging effects. Sufficient reactive power reserve should be made available to supply the increased reactive power demand and hence improve the voltage stability limit. The reactive power reserve of a generator is how much more reactive power that it can generate and it can be determined from its capacity curves. Simply speaking, the reactive power reserve is the ability of the generators to support bus voltages under increased load condition or system disturbances. The reserves of reactive sources can be considered as a measure of the degree of voltage stability.

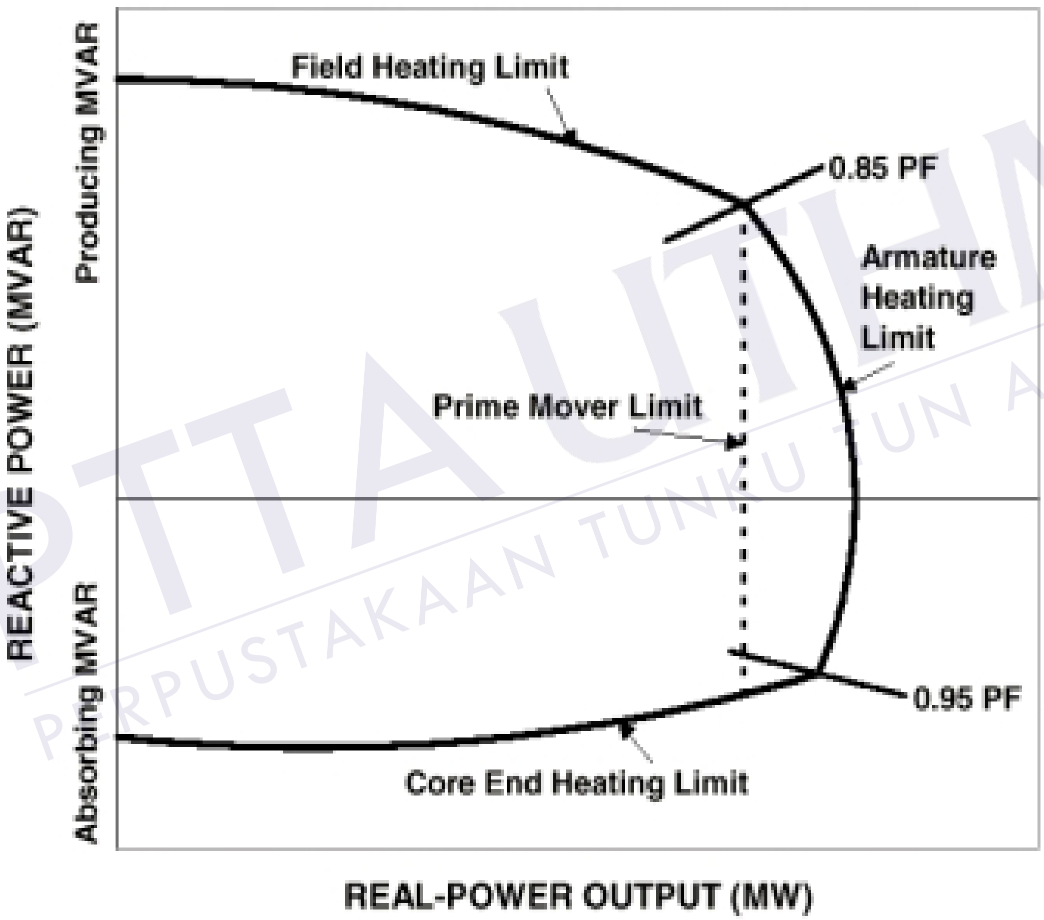

Figure 2.1: Reactive power capability dependence on real power production for a Synchronous generator [1].

Like most electric equipment, generators are limited by their current-carrying capability. Reactive power production is depended on the field heating limit and absorption on the core end-heating limit of the generator. Active power output limit is limited by armature heating.

Over the reactive output and the terminal voltage of the generator is provided DC current in the generator's rotating field. Control can be automatic, continuous, and fast. The inherent characteristics of the generator help maintain system voltage. At any given field setting, the generator has a specific terminal voltage it is attempting to hold. If the system voltage declines, the generator will inject reactive power into the power system, tending to raise system voltage. If the system voltage rises, the reactive output of the generator will drop, and ultimately reactive power will flow into the, tending to lower system voltage. The voltage regulator will accentuate this behavior by driving the field current in the appropriate direction to obtain the desired system voltage.

2.2.2 Power transfer components

The major power transfer components are transformers, overhead lines and underground cables. HVDC converter stations can also be treated as power transfer components.

2.2.2.1 Transformers

Transformers provide the capability to raise alternating-current generation voltages to levels that make long-distance power transfers practical and then lowering voltages back to levels that can be distributed and used. The ratio of the number of turns in the primary to the number of turns in the secondary coil determines the ratio of the primary voltage to the secondary voltage. By tapping the primary or secondary coil at various points, the ratio between the primary and secondary voltage can be adjusted. Transformer taps can be either fixed or adjustable under load through the use of a load-tap changer (LTC). Tap capability is selected for each application during transformer design. Fixed or variable taps often provide ±10% voltage selection, with fixed taps typically in 5 steps and variable taps in 32 steps.

Transformer-tap changers can be used for voltage control, but the control differs from that provided by reactive sources. Transformer taps can force voltage up (or down) on one side of a transformer, but it is at the expense of reducing (or raising) the voltage on the other side. The reactive power required to raise (or lower) voltage on a bus is forced to flow through the transformer from the bus on the other side. The reactive power consumption of a transformer at rated current is within the range 0.05 to 0.2 p.u. based on the transformer ratings.

Fixed taps are useful when compensating for load growth and other long-term shifts in system use. LTCs are used for more-rapid adjustments, such as compensating for the voltage fluctuations associated with the daily load cycle. While LTCs could potentially provide rapid voltage control, their performance is normally intentionally degraded. With an LTC, tap changing is accomplished by opening and closing contacts within the transformer's tap changing mechanism.

2.2.2.2 Transmission lines and cable

Transmission lines and cables generate and consume reactive power at the same time. Reactive power production is equal:

$$Q_{Gen=V^2B}$$

B – Shunt Susceptance.

$$Q_{Con=I^2X}$$

X – Line or cable Impedance

As we see from the expressions above reactive power generation is almost constant, because the voltage of the line is usually constant, and the line's reactive power consumption depends on the current or load connected to the line that is variable. So at the heavy load conditions transmission lines consume reactive power, decreasing the line voltage, and in the low load conditions – generate, increasing line voltage. The case when line's reactive power production is equal to consumption is called natural loading.

2.2.2.3 HVDC Converters

Thyristor-based HVDC converters always consume reactive power when in operation. The reactive power consumption of the HVDC converter/inverter is 50-60 % of the active power converted. The reactive power requirements of the converter and system have to be met by providing appropriate reactive power in the station. For that reason reactive power compensation devices are used together with reactive power control from the ac side.

2.2.3 Loads

Voltage stability is closely related to load characteristics. The reactive power consumption of the load has a great impact on voltage profile at the bus. The response of loads to voltage changes occurring over many minutes can affect voltage stability. For transient voltage stability the dynamic characteristics of loads such as induction motors are critical. Some typical reactive power consuming loads examples are given below.

2.2.3.1 Induction motors

About 60 % of electricity consumption goes to power motors and induction motors take nearly 90 % of total motor energy depending on industry and other factors. The steady-state active power drawn by motors is fairly independent of voltage until the point of stalling. The reactive power of the motor is more sensitive to voltage levels. As voltage drops the reactive power will decrease first, but then increase as the voltage drops further.

2.2.3.2 Induction generators

Induction generators as reactive power load became actual with the wind power station expansion into electricity sector. Wind plants are equipped with induction generators, which require a significant amount of reactive power. Part of the requirement is usually supplied by local power factor correction capacitors, connected at the terminal of each turbine. The rest is supplied from the network, which can lead to low voltages and increased losses.

2.2.3.3 Discharged lightning

About one-third of commercial load is lightning – largely fluorescent. Fluorescent and other discharged lightning has voltage sensitivity Pvin the range 1-1.3 and Qv in the range 3-4.5. At voltages between 65-80 % of nominal they will extinguish, but restart when voltage recovers.

2.2.3.4 Constant energy loads

Loads such as space heating, water heating, industrial process heating and air conditioning are controlled by thermostats, causing the loads to be constant energy in the time scale of minutes. Heating loads are especially important during wintertime, when system load is large and any supply voltage drop causes an increase in load current, which makes situation even worse.

2.2.3.5 Arc furnaces

Arc furnaces are a unique representation of problems with voltage stability, power factor correction and harmonic filtering. Rapid, large and erratic variations in furnace current cause voltage disturbances for supply utility and nuisance to neighboring customers. So the problem of voltage stabilization and reactive power control is usually solved by connecting the furnace to a higher network voltage, installing synchronous condensers and other fast responding reactive power generating units.

2.2.4 Reactive power compensation devices

Reactive power compensation intended effect on the balance of reactive power at the node power system to regulate the voltage and distribution networks and to reduce energy losses. To maintain the desired voltage levels at nodes electrical network consumption of reactive power must be provided the required power is generated with respect to the necessary reserve. Reactive power generated by the sum of the reactive power generated by the generators of power and reactive power compensating devices, placed in an electrical network in electrical and electric power consumers.

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