A NEW AHP – BASED REACTIVE POWER VALUATION METHOD

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A project report submitted in partial
Fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical & Electronic Engineering
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JANUARI 2013
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

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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

VsG3 - 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
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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](image)

Power Factor = Active power/Apparent power = kW/kVA
= Active power/ (Active Power + Reactive Power)


\[= \frac{kW}{(kW + kVAr)} \]
\[= \frac{TehTarik}{(TehTarik + Foam)} \]

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:

\[ Q_{Gen} = v^2 B \]

\[ B \] – Shunt Susceptance.

\[ Q_{Con} = i^2 X \]

\[ X \] – 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 $P_{\text{in}}$ in the range 1-1.3 and $Q_{\text{v}}$ 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.
2.2.4.1 Synchronous condensers

Every synchronous machine (motor or generator) has the reactive power capabilities the same as synchronous generators. Synchronous machines that are designed exclusively to provide reactive support are called synchronous condensers. Synchronous condensers have all of the response speed and controllability advantages of generators without the need to construct the rest of the power plant (e.g., fuel-handling equipment and boilers). Because they are rotating machines with moving parts and auxiliary systems, they require significantly more maintenance than static compensators. They also consume real power equal to about 3% of the machine’s reactive-power rating.

Synchronous condensers are used in transmission systems: at the receiving end of long transmissions, in important substations and in conjunction with HVDC converter stations. Small synchronous condensers have also been used in high-power industrial networks to increase the short circuit power. The reactive power output is continuously controllable. The response time with closedloop voltage control is from a few seconds and up, depending on different factors. In recent years the synchronous condensers have been practically ruled out by the thyristor controlled static VAR compensators, because those are much cheaper and have regulating characteristics similar to synchronous condensers.

2.2.4.2 Static VAR compensators

An SVC combines conventional capacitors and inductors with fast switching capability. Switching takes place in the sub cycle timeframe (i.e., in less than 1/50 of a second), providing a continuous range of control. The range can be designed to span from absorbing to generating reactive power. Advantages include fast, precise regulation of
voltage and unrestricted, largely transient-free, capacitor bank switching. Voltage is regulated according to a slope (droop) characteristic.

Static VAR compensator could be made up from:

1. TCR (thyristor controlled reactor);
2. TSC (thyristor switched capacitor);
3. TSR (thyristor switched reactor);
4. FC (fixed capacitor);
5. Harmonic filter.

Because SVCs use capacitors they suffer from the same degradation in reactive capability as voltage drops. They also do not have the short-term overload capability of generators and synchronous condensers. SVC applications usually require harmonic filters to reduce the amount of harmonics injected into the power system by the thyristor switching.

SVCs provide direct control of voltage. This is very valuable when there is little generation in the load area. The remaining capacitive capability of an SVC is a good indication of proximity to voltage instability. SVCs provide rapid control of temporary over voltages.

But on the other hand SVCs have limited overload capability, because SVC is a capacitor bank at its boost limit. The critical or collapse voltage becomes the SVC regulated voltage and instability usually occurs once an SVC reaches its boost limit. SVCs are expensive; shunt capacitor banks should first be used to allow unity power factor operation of nearby generators.
2.2.4.3 Series capacitors and reactors

Series capacitors compensation is usually applied for long transmission lines and transient stability improvement. Series compensation reduces net transmission line inductive reactance. The reactive generation $I^2X_C$ compensates for the reactive consumption $I^2X$ of the transmission line. Series capacitor reactive generation increases with the current squared, thus generating reactive power when it is most needed. This is a self-regulating nature of series capacitors. At light loads series capacitors have little effect.

2.2.4.4 Shunt capacitors

The primary purposes of transmission system shunt compensation near load areas are voltage control and load stabilization. Mechanically switched shunt capacitor banks are installed at major substations in load areas for producing reactive power and keeping voltage within required limits. For voltage stability shunt capacitor banks are very useful in allowing nearby generators to operate near unity power factor. This maximizes fast acting reactive reserve. Compared to SVCs, mechanically switched capacitor banks have the advantage of much lower cost. Switching speeds can be quite fast. Current limiting reactors are used to minimize switching transients.

There are several disadvantages to mechanically switched capacitors. For voltage emergencies the shortcoming of shunt capacitor banks is that the reactive power output drops with the voltage squared. For transient voltage instability the switching may not be fast enough to prevent induction motor stalling. Precise and rapid control of voltage is not possible. Like inductors, capacitor banks are discrete devices, but they are often configured with several steps to provide a limited amount of variable control. If voltage collapse results in a system, the stable parts of the system may experience damaging over voltages immediately following separation.
2.2.4.5 Shunt reactors

Shunt reactors are mainly used to keep the voltage down, by absorbing the reactive power, in the case of light load and load rejection, and to compensate the capacitive load of the line.

2.3 Voltage sensitivity

Electricity distribution networks are typically designed to meet customer demands in maintaining accurate voltage and frequency levels. Voltage drop in lines from distribution substations to customers is inevitable. However, the designers aim to limit this drop by redesigning and restructuring the networks and reconfiguring the feeders and loads.

By analyzing the voltage sensitivity of lines, the weakness of network voltage support may be identified and opportunities for improvement with real and/or reactive compensation through external active/passive elements can be examined. Voltages Sensitivities can be tested in system generator where the Voltage Sensitivities show the effect that an additional injection of real or reactive power at a bus has on real or reactive, or complex power flow on a particular line or interface [2].

2.4 PV Curves method

Increasing of loads and inter-utility power transfers leads to the transmission system stress. With growing size, along with economic and environmental pressures, the efficient operation of the system is becoming increasingly threatened due to problem of voltage instability and collapse. Voltage stability creates a serious problem in the ability
of a transmission line to transfer maximum power, particularly with higher VAR demand [1]. One of the most widely used voltage stability analysis tools today is PV curves.

The analysis in the PV curves tool can be done by varying system load or transfer and plotting it against voltage. Real power and voltage margin is obtainable from this analysis where the knee of the curve as reference point. Reactive power valuation by PV curve method can be done using voltage adequacy and stability tool (VAST) of the PowerWorld software. It is performed by increasing the load at the selected buses of the system and getting the response of the sources until the system reaches the limits and crashes.

2.5 Description of previous research and method

This section discuss about the previous research that had been carried out in reactive power valuation and the use of AHP method to determine the best choice of whatever situation where there are a lot of consideration to be made.

2.5.1 A new AHP- Based reactive power valuation method in restructured power system

S. Fatthiet.al [2] proposed a new approach for reactive power valuation and reactive source classification. The analysis was based on OPF, different methods of power system analysis and analytic hierarchical process (AHP). In this project proposal suggest that three generators will be used as a power reactive source. Meanwhile the value of reactive power support will be determined based on the four factors which are Voltages Sensitivities, Voltage Adequacy and Stability, Equivalent Reactive Compensation
(ERC) and Backup generation. All the value obtained from the determination will be analyzed and categorized using AHP method.

2.5.2 The effect of reactive power generation modeling on voltage stability analysis

Problems related to voltage instability in Electrical Power Systems are today, in many countries, one of the major concerns for power system planning and operation. T. G Eduardo [5] in his paper mention that during the last decades there have been black outs caused by voltage instability problems throughout the world. From analysis of this phenomenon, the following factors can contribute to long term voltage instability problems: high active and reactive loading, operation of on load tap changer transformers, inadequate locally available reactive power resources, load characteristics at low voltage magnitudes and operation of relay protection.

The use of PSO based optimization algorithm to solve the problem of optimal reactive power planning including the placement and sizing of SVC and TCSC device in a medium size power network for voltage stability limit improvement by controlling the reactive power flow and reducing the real power loss has been proposed in European Journal of Scientific Research. The research proves that voltage stability limit improvement is more effective when it is done both by control of reactive power generation and reactive power flow.

2.5.3 Impact on generator reactive power limits on a static voltage stability

Voltage stability margin in a power system is closely related with the availability of reactive power in the system. G. Jorge et al [6] use an adequate modeling of the reactive power sources in their studies. The Minimum Singular Value of the load flow Jacobian
matrix has been commonly used as a static voltage stability index. In the paper, such index is used to assess the influence on the static voltage stability limit of modeling the generators reactive power limits by its capability curve. Simulation results on a test system indicate that modeling the reactive power limits of the generating units by the simplified Qmin/Qmax approach, commonly used by most of the load flow programs, yields optimistic values for the voltage stability index.

2.5.4 Analytic hierarchy process based on fuzzy logic

The issue of Analytic Hierarchy Process for decision making problems is the long-standing question under study. Natali Mironova [8] improved Analytic Hierarchy Process based on fuzzy logic in this paper. In the task of making management decisions and prognoses of possible results, a person that takes the decision (PTD) usually has to deal with the complex system of interdependent components (resources, required results or goals), that has to be analyzed. Traditional Analytic Hierarchy Process (AHP) introduced by Saaty reduces complex systems analyzing to the number of pairwise comparisons of their parts. AHP consists of the next steps: hierarchy forming, matrix of pairwise comparisons (MPC) constructing, vector of priority calculating, consistency ratio evaluating, alternative perceptibility analysis. There are two approaches to the local vector of priorities calculating: approximate methods and methods based on matrixes. MPC consistency ratio evaluating is realized by the means of approximate evaluating of the maximal eigenvalue $\lambda_{\text{max}}$ maximum value, consistency index $CI$, consistency ratio $CR$.

The main advantage of the traditional approach AHP lies in its simplicity. It also can be mentioned that AHP conforms to intuitive presentation of the problem solving and is used successfully for many tasks (manufacturing resources planning, HR decisions taking, optimal strategy choice, etc.) Disadvantage of the approach lies in its inability to present sufficiently inconsistency and fuzziness of judgments resulting from presentation of PTD judgments as exact numbers. In the AHP traditional formulation
expert judgments are presented as exact numbers, but in solving of many practical problems PTD presentation model is often uncertain and judgments presentation as exact numbers may occur a complicated and sometimes impossible task. In choosing one variant from the set of alternatives PTD may be confronted with the situation of uncertainty in estimation of there level of preference among each other because of incomplete or imperfect data. That is why it is offered to present expert comparison relations as fuzzy set or fuzzy numbers [8].

2.5.5 Application of analytic hierarchy process in power lines maintenance

In this paper Analytic hierarchy process (AHP), an effective method that can solve a multiple criteria and multiple objective decision-making problems was introduced to the power lines maintenance problem in order to gain a scientific and objective maintenance scheduling. Firstly an AHP model was built up on the base of analyzing correlative factors. Then an example was given to indicate how AHP to apply.

According to Zhiling Lin et. Al [9] By putting quality and quantify together, AHP is an efficient system analysis method. AHP is mainly used for analyzing and dealing with many affecting factors, resolving multiple criteria and multiple objective decision-making problems. There are many factors on affecting the power lines maintenance, and their relations are very complex. That an AHP method is introduced to the power lines maintenance is a beneficial search to build a scientific and objective evaluation mechanism in the complex system.
2.5.6 Using the analytic hierarchy process for evaluating multi-agent system architecture candidates

A study by P. Davidson et al [10] show that though much effort has been spent on suggesting and implementing new architectures of Multi-Agent Systems (MAS), the evaluation and comparison of these has often been done in a rather ad-hoc fashion. The writer investigate the problem of load balancing and overload control of Intelligent Networks and present four MAS architectures that can be used to handle this task. They instantiate each of these and define metrics for the selected quality attributes.

The instantiations are studied in simulation experiments and measurements of the metrics are recorded. The measurements are then analyzed using the Analytic Hierarchy Process, which is a basic approach to select the most suitable alternative from a number of alternatives evaluated with respect to several criteria. In this paper the writers illustrate how such analyzes can be used for deciding which architecture candidate is the most appropriate in different situations.

2.5.7 An AHP-based study of WCM implementation factors in ISO 9001 certified manufacturing organizations in Trinidad and Tobago.

K. Ramoutar [11] has emphasised in this paper the importance of measuring the different facets of organizations performance in order to achieve a competitive advantage. Without the ability to understand or measure performance, reorientation or diversification of a company’s strategies, operations, process, procedures and even benchmarking will be futile. The need for effective deployment of business objectives down through the organization and the subsequent measurement of the organization’s performance is well documented as key elements of sustainable competitive advantage. WCM focuses on continuous improvement. Hayes and Wheelwright (1984) introduced the term WCM to describe organizations which achieved a global competitive advantage
through use of their manufacturing capabilities as a strategic weapon and described this as a set of practices that focus on continuous improvement, training and investment in technology. Numerous studies have found that the implementation of WCM practices has led to superior performance.

K. Ramoutar [11] conducted a recent study on WCM implementation criteria and related sub-criteria in ISO 9001 certified manufacturing organizations in T&T. The aim of the study was to collect empirical evidence and consolidate a breadth of credible opinions on criteria towards the successful implementation of WCM practices in manufacturing organizations. The AHP methodology was used to determine the extent to which the criteria and subcriteria of WCM implementation had affected the ISO 9001 certified organizations. The AHP methodology involves the decomposition of a complex problem into a multi-level hierarchical structure of characteristics and criteria.

2.5.8 Study on project experts’ evaluation based on analytic hierarchy process and fuzzy comprehensive evaluation.

According to Tianbiao Yu et. al [12] to assure justice and science of scientific and technological project evaluation, avoiding the corrupt transaction in the process of project evaluation, it is necessary to evaluation the experts’ performance with a scientific method. The main factors that affect the experts’ performance evaluation were analyzed. To avoid the effect of individual subjective judgment and favoritism on the result of the experts’ performance evaluation, a method of the experts’ performance evaluation based on analytic hierarchy process (AHP) and fuzzy comprehensive evaluation (FCE) was proposed. The AHP was used in this paper to determine the weight of each evaluating index, and the FCE method was applied to the information processing of the experts’ performance evaluation. After that, the FCE mode of the experts’ performance was established. Based on these a prototype system is developed, results of the system running prove the correctness of theory study and feasibility of technology research. The study works provides a scientific and reliable method of the project experts’ evaluation.
2.5.9 Research and development evaluation at an early stage using the analytic hierarchy process (AHP)

Horikawa S. [13] in his paper said that problems seem to be emerged that the outcomes of research and development (R&D) do not relate to new products and profit in the manufacturing industries. Generally, the R&D targets and their specifications cannot be clearly set by engineers because they need to design new product and its specifications several years in advance. At an early stage of R&D which is important to build competitive priority, an evaluation method securely connecting the R&D with new product and profit is needed. The Analytic Hierarchy Process (AHP), expected to be an effective decision-making support tool, was applied to evaluate R&D themes at an early stage. The correlation was obtained between the R&D results and AHP scores. The AHP was found to be an effective tool for decision-making of R&D as a gate of each early stage.

Current market globalization, accelerated diversification of social and customers needs, and short product life cycle significantly increase market and technology uncertainties. Companies are wanted to overcome the uncertainties for keeping and strengthening their competitiveness. Problems seem to be emerged that the outcomes of research and development (R&D) do not relate to new products and profit. Consequently, evaluation and decision-making at an early R&D stage have become especially important.

The target specification of R&D theme cannot be clearly set by engineers even if they are directly engaged in the R&D because they need to design new product and specifications several years in advance. At an early R&D stage, decision-making such as evaluation and determination must be done based on uncertain information. This makes decision-making in R&D stage extremely difficult[22]. In order to evaluate R&D themes at an early stage, we applied the Analytic Hierarchy Process (AHP) expected to be an effective decision-making supporting tool under high uncertainties. Correlation was obtained between the R&D results and AHP scores. Based on the quantitative criteria, decision-making was easily done at an early stage.
2.5.10 An improved ranking approach to AHP alternatives based on variable weights

The conventional analytic hierarchy process (AHP) has the drawback of its invariabe weights system (IWS) and the composite ranking approaches based on IWS, incapable of reflecting intrinsic characteristics of complex evaluation issues, such as nonlinearity, emergence, etc. To overcome the above drawback, with the idea of weight varying adopted, an improved ranking approach to AHP alternatives based on variable weights is given by the way of constructing a variant analysis structure of AHP evaluating problems and its corresponding value system for evaluating alternatives. Compared with the conventional AHP, not only does the improved approach adopt the variant analysis structure and the new extracting way for experts’ information, which can better reflect the characteristics such as emergence and nonlinearity, but also in essence it well solves the AHP rank reversal problem and concept definitions of adopted weights are clear as well. Applied to a real example, the improved approach is validated to be applicable[14].

2.5.11 Impact on generator reactive power limits on a static voltage stability

Voltage stability margin in a power system is closely related with the availability of reactive power in the system. Therefore, adequate modeling of the reactive power sources becomes an important issue in this studies. The Minimum Singular Value of the load flow Jacobian matrix has been commonly used as a static voltage stability index. In this paper, such index is used to assess the influence on the static voltage stability limit of modeling the generators reactive power limits by its capability curve. Simulation results on a test system indicate that modeling the reactive power limits of the generating units by the simplified Qmin/Qmax approach, commonly used by most of the load flow programs, yields optimistic values for this voltage stability index.


