IMPROVEMENT OF POWER QUALITY USING UPFC IN A MULTI BUS DISTRIBUTION SYSTEM

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ABSTRACT

The application of the unified power flow controller, UPFC, which is one of the flexible AC transmission systems devices, FACTS, to solve the voltage drop and to reduce power loss is developed. The IEEE 14-bus and 6-bus test systems are used for analysis using MATLAB Simulink software. Most of the power quality disturbances cause power loss increase in power systems. Among the power quality disturbances the voltage sag is the most common problem faced by the utilities. Moreover, the power loss reduction is one of the approaches considered by the utilities in their planning. In this research, two different situations are considered for both systems; without the application of UPFC device, and with the application of UPFC. The real and reactive power losses in the whole system are calculated for both situations, and the comparative results are provided. The system performance is also studied for different placement of the UPFC. In addition, the main capability of the UPFC which is injecting a variable voltage in series with the point of connection in network is examined and the power loss is measured in different injected voltages. The variation of the voltage is in the term of the voltage magnitude and phase angle. Simulation results have demonstrated that the application of UPFC has a desirable impact on power loss reduction in the power systems.

ABSTRAK

Penggunaan pengawal aliran kuasa bersatu, *UPFC*, yang merupakan peranti Sistem Penghantaran Fleksibel AU, *FACTS*, untuk menyelesaikan kejatuhan voltan dan untuk mengurangkan kehilangan kuasa telah dibangunkan. Sistem ujian *IEEE* 14-bas dan 6-bas digunakan untuk analisis dengan menggunakan perisian *MATLAB* Simulink. Kebanyakan gangguan kualiti kuasa boleh menyebabkan peningkatan kehilangan dalam sistem kuasa. Antara gangguan kualiti kuasa, voltan lendut adalah masalah yang paling biasa dihadapi oleh utiliti. Selain itu, pengurangan kehilangan kuasa adalah salah satu pendekatan yang diambilkira oleh utiliti dalam perancangan mereka. Dalam kajian ini, dua keadaan yang berbeza telah dipertimbangkan untuk kedua-dua sistem; keadaan tanpa penggunaan peranti *UPFC*, dan dengan penggunaan peranti tersebut. Kerugian kuasa sebenar dan kuasa reaktif di seluruh sistem dikira untuk kedua-dua keadaan, dan keputusan perbandingan disediakan. Prestasi sistem juga dikaji untuk penempatan *UPFC* yang berbeza. Di samping itu, keupayaan utama *UPFC* yang disuntik dengan voltan berubah-ubah secara sesiri dengan titik sambungan dalam rangkaian diuji, kehilangan kuasa diukur untuk nilai suntikan voltan yang berbeza-beza. Nilai perubahan voltan adalah dari segi magnitud voltan dan sudut fasa. Keputusan simulasi menunjukkan bahawa penggunaan *UPFC* mempunyai kesan yang wajar keatas pengurangan kehilangan di dalam sistem kuasa.

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Vs	-	Sending end voltage
V_R	-	Receiving end voltage
I_S	-	Sending end current
I_R	-	Receiving end current
S_S	-	Sending end apparent power
S_R	-	Receiving end apparent power
3ϕ	-	Three Phase
S_L	-	Line apparent power
η	-	Efficiency
P_S	-	Sending end active power
P_R	-	Receiving end active power
Ia	-	Current of phase a
I_b	-	Current of phase b
Ic	-	Current of phase c
I_0	-	Zero sequence current
Q	-	Reactive power
r	-	Injected voltage magnitude
γ	-	Injected voltage phase angle

CHAPTER 1

INTRODUCTION

1.1 Introduction

Power quality improvement is one of the current issues in electricity industry. The different engaged sectors in this industry including energy supply side consisting of the generation, transmission, and distribution on one side and the electricity consumers and the electrical equipment manufacturers on the other side, all try to provide, deliver, and consume the electricity in an acceptable range of quality. The power quality disturbances are produced and propagated in the power system network from a bunch of sources and with different significances. The correction of these disturbances can be done also in various stages and location of the power network. In this project the power distribution network is considered to be simulated, and one of the flexible active compensating devices, unified power flow controller, UPFC, is going to be installed and the performance of the compensator will be measured in MATLAB and discussed. The project report provides the theoretical study on the subject and the simulation result.

1.2 Background of problem

Historically the new approach in dealing with power quality issues has started from 1890 which the voltage and current standard levels were defined. Hundred years later the voltage drop limits were standardized on 1990. The extended power networks in the wide areas to supply demands and the diversity of the electrical end user devices have caused different power quality phenomena happen and exist in the power media. With the needed proficiency level of study and dealing with electricity related issues, many academic and specialist researchers have been attracted to study, experiment and develop the power quality improving methods and instruments. As it is briefly provided in the literature review, chapter 2, there are several papers which conduct individual studies on this field which specifically simulate a limited power system including a power quality compensator device or practically install and measure the performance of the compensator. As far as the researcher has found in the online libraries and databases, some of the studies are done in transmission power network, and less some in distribution. In the distribution sector, the studies include the measurement and analysis of the parameter in two buses in the network.

1.3 Statement of problem

In power distribution system, improving the power quality is an effective act in satisfying the customers' interests. On the other hand, from the utilities' point of view, the disturbance and weakness correction in the power network can improve the performance of the system and reduce power and energy losses and voltage drops. When a correcting device such as UPFC is used in a section of the system, the influence of its compensating capability on neighbouring buses and feeders in the term of voltage regulation can be measured. This project provides the whole simulated system improvement in the matter of power loss and voltage drop decrease by the measuring tools of the MATLAB in the case of installing a UPFC and compares two states of system; without UPFC, and with UPFC.

1.3.1 Some of the utilities' concerns

1.3.1.1 Power loss

In power distribution systems power loss is one of the main issues and objectives which is concerned in strategic planning of the power industry and is controlled as far as the possible in system. Moreover the operation of the existing system, its loading, expansion, and maintenance procedures are significantly coordinated with the consideration of power loss control and reduction aim in the utility companies. In any part of the distribution system, the delivered power in sending end and receiving end of the a specified segment of the line can be calculated using the equations 1.1 and 1.2; in these equations V_S, V_R, I_S, I_R are, sending end voltage, receiving end voltage, sending end current and receiving end current respectively. S_S is the apparent power which is injected to the system from source side of the line and S_R is the apparent power which is delivered to the load point at receiving end of the line which is demand side.

$$S_{S(3\phi)} = 3V_{S(phase)} I^*_{S(phase)} \qquad 1.1$$

$$S_{R(3\phi)} = 3V_{R(phase)} I^*_{R(phase)} \qquad 1.2$$

The apparent power loss in the line and the line efficiency are calculated via equations 1.3 and 1.4 respectively;

$$S_{L(3\phi)} = S_{S(3\phi)} - S_{R(3\phi)} \qquad 1.3$$

$$\eta = \frac{P_{R(3\phi)}}{P_{S(3\phi)}} \qquad \%\eta = \frac{P_{R(3\phi)}}{P_{S(3\phi)}} \times 100 \qquad 1.4$$

It is seen that to have a high efficiency distribution line, the power loss of the line must be reduced which means the delivered power to the receiving end be as close as possible to the supplied power at sending end. To fulfil this condition assuming the line model as short line model which is characterized with an equivalent impedance including an inductance in series with a resistance, the receiving end voltage should be hold same as sending end voltage while the current flow through the line is considered constant. Application of any controller or compensator apparatus with appropriate design and parameter which influence the line voltage or even current can modify and condition the power flow in the line and limit the power loss of the line long.

1.3.1.2 Load unbalance

Uneven phase current distribution in multiphase systems leads to higher power and energy loss in current carrying devices compared to the state of balanced current system. In general three phase four-wired distribution lines, the unbalance current flow in phases cause the zero sequence current flow in neutral wire. The ground wire current is not employed in any effective and useful application, though it is a power loss component which is wasted as heat and is finally discharged via earth path to ground. The single phase/ two phase expansion of the power system, connecting the single phase customer’s service line in a non-equal number and load magnitude to three phase system, and three phase unbalanced loads are the origin of the unbalanced current flow in the distribution systems. Moreover some system failures and problems in a balanced loaded network can result the unbalanced phase current in a three phase system. When an unbalance condition is occurred, the ground current which is equal to the zero sequence current is calculated using the equation 1.5;

$$I_{neutralwire} = I_{0(zerosequence)} = \frac{1}{3}(I_a + I_b + I_c) \qquad 1.5$$

Where I_a, I_b, and I_c are phase current vectors. In a balance system the summation of three phases’ currents is zero. This means that there is no current passing the neutral wire. Whatever the system unbalance situation is more severe the resultant neutral current is larger. Power loss in neutral wire is calculated using the formula given in equation 1.6;

$$P_{neutralwire\,loss} = I^2_{neutralwire} * R_{neutralwire} \qquad 1.6$$

Where $R_{Neutral\ wire}$ is the resistance of neutral wire. To reduce this loss in power systems two approaches can be employed; one approach is, decreasing the neutral wire resistance which can be done by changing the neutral conductor with a larger cross section wire, and/or with a conductor with lower resistivity and higher conductivity. Another approach is reducing neutral wire current which can be achieved by balancing the phase currents. Balancing the currents can be done by implementing power flow conditioner devices on the system.

1.3.1.3 Harmonics

To define the distortion of voltage and current waveform mathematically, harmonics are introduced. The basis of describing the harmonics is the frequency of a waveform. Harmonics’ orders are integer multiples of the fundamental frequency of the waveform and refer to the components of a waveform that occur at different frequencies. Based on the Fourier theory, any repetitive waveform can be defined as summation of sinusoidal waveforms which are integer multiples (or harmonics) of the fundamental frequency. Non-linear loads in power systems produce harmonics. The portion of these loads in total demand has dramatically increased. Application of ever growing diversity of electrical appliances which use power electronics controlling circuits has caused the problem of distortion in the electrical parameters of supplied power in distribution systems.

Non-linear loads which are the source of propagation of distorted current waveform in feeders draw non-sinusoidal currents from a sinusoidal voltage source. Some examples of harmonic producing loads are electric arc furnaces, static VAR compensators, inverters, DC converters, switch-mode power supplies, and AC or DC motor drives.

IEEE Std. 519-1992, which is titled "IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems", is the main document for harmonics. This standard serves as an excellent tutorial on harmonics. The most important part of this document to the industrial user is Chapter 10 "Recommended Practices for Individual Consumers". This section puts limits on individual and total distortion for current harmonics. Harmonics should be kept under reasonable limits at the point where the power system feeds different costumers, however any distortion that is propagated in the system can affect all the customers which are connected to this system. Installing power flow controller devices in any part of the network can protect any sensitive load connected to this part and also can restricts entry of waveform distortions from the load side to supply side. This dual compensation arises from the both voltage and current compensation capabilities of the conditioner device. In this manner both power system and loads take advantages of the operation of this device in the system, and for the load side part where ever there is any obligation for filtering the current drawn by the customer by the related customers, the capital and maintenance costs of power flow controller device can be shared by the utility and the customers.

1.3.1.4 Critical urban areas

Distribution companies are the forehead of power systems and the most immediate sector of power supply industry which is in a widespread contact with electricity customers. Every single power service point has an identity in distribution company data bank and is supposed to be supplied with standard quality of electric power which is ideally continuously provided without any interruption. Among the numerous electricity clients and different areas which distribution companies have spread their power system and cover the demands' provision, there are some customers and some places which have higher priority regarding the necessity of stable and reliable feeding compared to other costumers. The following list is an example of them;

- Crowded areas in city centres which covers a heavy traffic of citizens and cars
- Public transportation centres and facilities which transfer a large number of passengers in city
- Hospitals, clinical and rehabilitation centres which provide vital services
- Banks which support the financial activities and are the fundamentals of trading and business
- Schools which should be kept a comfortable and safe gathering place for children
- Military and strategic centres which their performance is critical for social security

Any disturbance in the power system in these places along with the demand growth which is caused by the welfare improvement, developing new services and increasing the costumers' population in the location can result in low power quality power supply flowing in the distribution network. Improving the voltage level in the case of voltage sag in these areas, compensation of waveform distortion and balancing the power flow are some of the main operational strategies and plans which can be done using power flow conditioner devices.

1.3.1.5 Land providing problem

In some city centres and power system sections which usually consist of commercial customers and are the business centres of the area, the existing substations and feeders can’t deliver an acceptable and standard quality of electricity therefore it is needed to support the power system with extra networks. To establish the network especially for the ground-mounted substations in some areas, there are difficulties such as availability of any appropriate place and if it is available, the cost of land in the location is very high in certain areas. As the power system analysis determines the best location of distribution network expansion, providing the exact place might not be feasible practically. In these cases, facilitating the existing network with proper power conditioner and controller devices is one of the applicable alternatives which manage improving system electrical parameters. Cost-benefit analysis along with the technical reports of the empowered network can justify the chosen design and plan in the possible methods of system development.

1.3.1.6 Excavation limitation

One of the usual constraints in developing electricity distribution networks is the excavation limitations. In certain areas in city centres to avoid of the interference with the existing utilities network of electricity, water, sewage, communication and any other underground systems installing any extra underground network is impossible. Moreover to establish a new underground line in the crowded areas it is needed to arrange and coordinate with municipal authorities to change some traffic routs and provide substitute ways for the transportations and pedestrians. Implementation of these acts is costly and has many difficulties in practice. In these situations application of power flow controllers is beneficial and provides the possibility of utilization of the existing network in higher efficiencies. These equipment can improve the power flow balance in three phase systems, compensate the reactive power demand of loads, reduce the voltage drop in the existing networks and reduce the waveform distortion level of the delivered voltage and also they can decrease the current waveform problems. In the cases that any of these problems is the reason of planning additional power distribution section, power conditioner devices are alternative option and if they are installed at proper locations and characterized with appropriate parameters the consequence is that the network problem is eliminated without adding new lines to the distribution systems.

1.3.1.7 Faults in distribution system operation

One of the most common problems that occur occasionally in power distribution networks is fault. Different reasons contribute in fault occurrence. Some of these reasons include;

- Proximity of overhead lines to tree branches
- Existence of the buildings and other infrastructural establishments in overhead lines neighbourhood
- The contact of constructional vehicles with overhead networks
- Birds and animals which touch at least one phase and another phase or ground conductors
- Drilling equipment which touch the underground power system elements
- Any municipal services’ constructive procedure which interfere with power system
- Insulation failures
- Lightning strike or switching surge which destroy insulators of the lines and touch the phases
- Contamination of the power system insulation

The fault occurrence depending the fault type, impedance and severity causes different voltage drop levels in power systems. If the faulty circuit draws a large value of current from the source side, the circuit protection relay operates and sectionalizes the faulty section from the whole system. The current limit is defined and the protection is set regarding this limit. More the fault current is, faster the protection acts. Sometimes the fault is not large enough to be identified by the protection devices, or it is occurred far enough in long line distribution networks from the substation which feeds the line. In this case, fault causes voltage drop and remains as long term variation or steady state problem. Comparing different voltage drops in power systems, fault caused voltage drops are the worst regarding the magnitude in distribution networks.

1.3.1.8 Voltage Drop

Voltage drop can occur in the power system because of loose connections, overloading, and load imbalance.

Loose connections are created in the following circumstances;

- Loose connection between cable terminals and bus bars
- Crimped connections of conductors
- Improper adjusted contacts in switches, sectionalizing equipment, re-closers, fuses and circuit breakers
- Dirty or corroded connections in switches.

To supply load demand, when the power system voltage has dropped from its standard limits, the electrical appliances which need a certain level of voltage to work properly, draw larger current which is needed to satisfy the load power demand. The larger current value creates higher power and energy loss in the system and also causes appliances insulation degradation and reduces the system efficiency. One of the main applications of power flow controller devices can be the compensation the voltage drop in the distribution systems.

1.3.1.9 Load balance and voltage control

Traditionally in distribution systems, power flow control is done manually by disconnecting the individual loads or sectionalizing the service line sections. The proper load value curtailment is decided through the system operation experts' experience or by measuring the current flow in different sections. If any power electronics-based control devices such as UPFC is used, the power flow control can be conducted automatically and in anytime without the need of operator interference and presence.

The power system especially in distribution section includes numerous loads that are spread in the network long. The voltage level at different places in a particular distribution line varies from point to point of services' couplings. The length of conductor, the cross section area, the load magnitude and the conductor type determine the voltage drop level. At the distribution panel which is placed at the joint point of lines and substations, usually the voltage is kept within standard limits by controlling the secondary voltage of the transformer in substation and other stationary compensating equipment such as reactor and capacitor banks, therefore the voltage level normally satisfies the standard limits. In this place the metering is provided and depending on the voltage level, full time monitoring and control personnel and/or scheduled cycle inspecting and measurement are done. The network voltage control along with the feeders in the places away from the distribution boards is done usually by customers' feedback and also by some scheduled on-field measurement if there is any and if is conducted.

The voltage control and improvement can be done using FACTS devices such as UPFC. In this case the automatic voltage drop compensation will be done in the location of device installation.

In the mission of automation of distribution system performance control and management, the system control is planned to be done as automated as possible. The power electronics-based devices can be employed to fulfil this objective and leads the distribution system to automation. The automated system is more substantial if the network is going to develop to smart grid network.

1.3.1.10 Competitive electricity market

Many developing countries are moving toward competitive market in supplying electricity to customers. Successful participating in electricity market needs some requirements such as providing high quality services and increasing power system efficiency. In the electricity market, because of deregulation, the utilities costs are not supplied by government anymore. In the traditional electricity market whatever the power system efficiency is, the electricity price is determined by government and the utilities' expenses if not satisfied from the utilities' income, are compensated by the government and therefore the power system operation, development, and maintenance are afforded by utilities. However in competitive electricity markets in order to have higher benefits, utilities have to reduce power system losses and they have to provide standard level of voltage to their customers, service points. To fulfil these aims, taking advantages of power electronics-based devices such as UPFC are considered.

1.3.2 Utilities' measures

According to above mentioned situations, in practice, strategic planning and operating of the distribution networks necessitate the power system planners and operation managers consider variety of variables and employ different plans to support the system proper operation and respond the costumers' reasonable demand. The most straight forward solution is installing extra system components in power network. These components include; transformers, overhead lines, underground cables, and other related system elements. The second common feature is substituting the existing component and elements with larger capacity devices. Sometimes the limitations, side effects and the executive costs and problems justify using power flow controller devices instead of conducting network development. In these cases one of the adjustable and versatile controlling devices which can be employed is UPFC. This device is employed to conduct some of the corrective measures of the utilities in technical, executive and strategic approaches which are defined in figures 1.1 to 1.3.

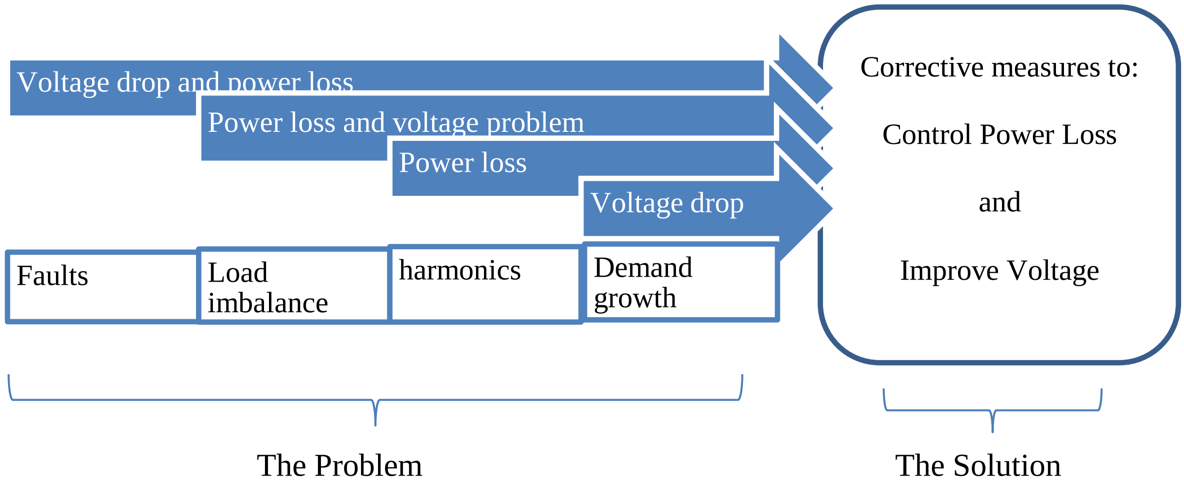

Figure 1.1: Some of the utility technical concerns and their solution

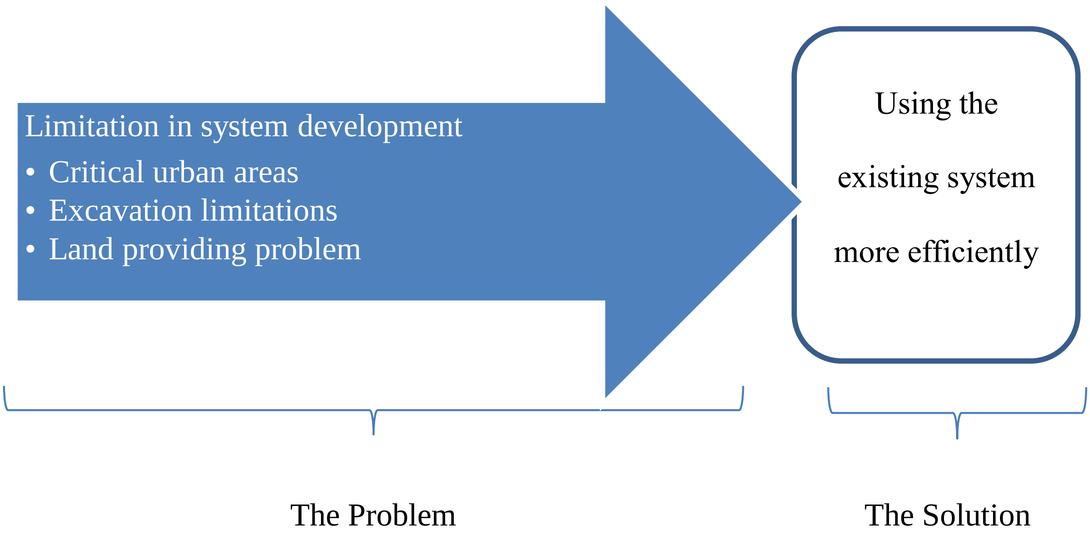

Figure 1.2: Some of the utility executive concerns and their solution

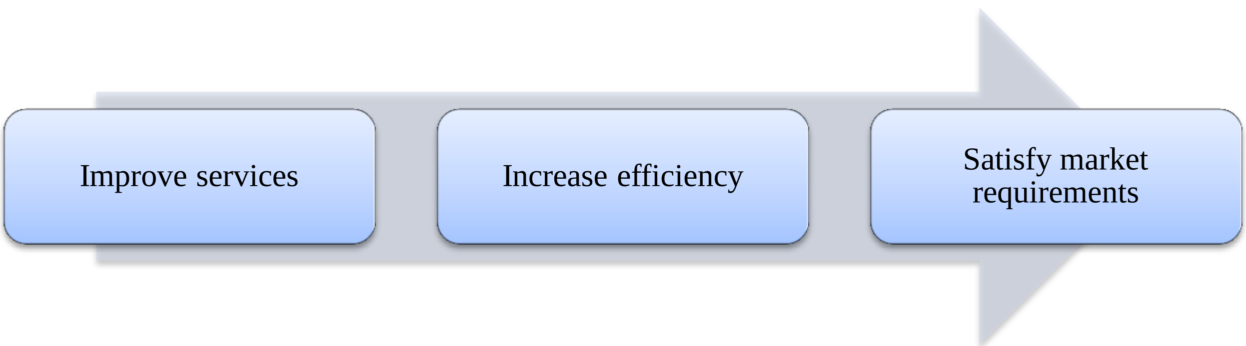

Figure 1.3: Electricity market strategic approach

1.4 Objectives

The main objectives of this project are;

- To simulate a distribution network with the proper physical and functional parameters
- To use UPFC device in the simulated network
- To run the system and measure the electrical parameters of the compensated network
- To analyse the performance of the system with and without UPFC regarding the bus voltage and power losses

1.5 Scope of the Study

The study is implemented with a typical distribution network data using the IEEE multi bus system data and per unit network parameters which are accessible and can rely on their accuracy. The network data and simulating software provide the input data of implementing the research objectives and get the required base of analysis.

1.6 Conclusion

To have a high quality power supply and delivery circumstances in utilities' network territory, by this project, the researcher provides a study on the application of UPFC device. The performance of the system the whole buses in the network is measured and analysed and the research results can be used by the planning and technical departments of the utilities. Although the results are obtained in simulation space, they still have the advantage of real time measurement and accuracy of analysis of simultaneous provided data.

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