Cold Load Pick-up

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by

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Abstract

The load behaviour of the industrial and residential sector following different types of outages is dealt with in this dissertation. Data on the power consumption after these outages have been used for deriving models of the cold load pick-up.

In the industrial sector the investigation covers a variety of branches and special attention has been given to plants having a high degree of electric energy consumption. Data of the power consumption after planned and forced outages have been collected and descriptions over typical restarting procedures and common restoration problems have been summarized. Due to the fact that the production can not start immediately after voltage is restored, the power consumption from the industrial sector will be lower after an outage as compared with the pre disturbance condition. The time it takes to enter a normal production again varies considerably and may take minutes or up to days for sensitive processing industries.

When studying the residential sector, individual load objects, individual houses and residential areas have been investigated by laboratory and field measurements. The reason for this is to get a better understanding of how different load objects and electric heating behave after an outage. This knowledge is then used when analysing measurements of the cold load pick-up in residential areas. The measurements clearly indicate that the cold load pick-up for residential load has the opposite behaviour as compared with industrial load which means that it is (much) higher after an outage and then decreases to its normal level after a time.

As residential load often is used in schemes of rotating load curtailment, simulations of such a scheme have been performed. The results show that it is important to tune this scheme properly in order to achieve the desired operation.

Keywords: Blackout, cold load pick-up, field measurements, load modelling, power system restoration.

List of Publications

A Agneholm E., Daalder J., **Cold Load Pick-up for Individual Load Objects**, 33rd Universities Power Engineering Conference, September 8-10, 1998, Edinburgh, United Kingdom. Proceedings Vol. 1, pp. 53-56.

B Agneholm E., Daalder J., **The Load Behaviour of Electric Heating following a Disturbance**, submitted to IEE Proceedings-Generation, Transmission and Distribution.

C Agneholm E., Daalder J. **Cold Load Pick-up of Residential Load**, submitted to IEE Proceedings-Generation, Transmission and Distribution.

D Agneholm E., Daalder J., **Load Recovery in the Pulp and Paper Industry following a Disturbance**, submitted to IEEE Transactions on Power Delivery.

E Agneholm E., Daalder J., **Load Recovery in Different Industries following an Outage**, submitted to IEEE Transactions on Power Delivery.

Preface

The work presented in this thesis has been carried out at the Department of Electric Power Engineering at Chalmers University of Technology. The research has been funded through the Elforsk Elektra program which is jointly financed by the Swedish National Board for Industrial and Technical Development (NUTEK) and the power companies in Sweden. The financial support is gratefully acknowledged. Travelling money for joining conferences and courses have been supported by Chalmers anslag för forskarstuderandes resor, Letterstedska resestipendiefonden, Adlerbertska forskningsfonden and Clas Adelskölds minnesfond.

I would like to thank Professor Bertil Stenborg, Dag Holmberg and Kenneth Walve who initiated the licentiate project which was the start of my Ph. D studies a couple of years ago. When Bertil retired Professor Jaap Daalder succeeded as my supervisor. I wish to express my deepest gratitude to you Jaap for supervising this work, for valuable comments, fruitful discussions and for persistently revising the manuscript.

Members of the reference group have been Tesfai Embaie, Hans Fendin, Hans Elmvik and Jan Djurström. Thank you all for fruitful discussions and valuable comments.

The work presented is highly related to field measurements. I would like to thank all the industries and power companies which have supplied me with data; the families which have given me the opportunity to perform measurements in their houses; and Vattenfall Regionnät AB, Göteborg Energi Nät AB, Lerum Energi AB and Gullspång Nät AB for the cooperation received in performing field measurements in residential areas.

Finally I would like to thank all the colleagues at the department of Electric Power Engineering. It has been a privilege to work with you all.

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Paper E Load Recovery in Different Industries following an Outage

Chapter 1 Introduction

1.1 Background

The work reported here is a continuation of a licentiate thesis which was presented in 1996 [1]. The project started in 1993 and deals with the restoration of a power system after a partial or a total blackout. The thesis gives an overview of the Swedish electric power system including frequency control, available reactive resources and automatic equipment installed in the system and used for saving the system in severe situations. Alternatives of restoring a power system after a blackout are treated and a description of the last two Swedish blackouts experienced is included.

After a major breakdown it is possible to start the restoration process if assistance from neighbouring areas by tie lines is available, part(s) of the system have succeeded in establishing island operation or if there are stations with blackstart capability. The licentiate thesis gives a description of different island operation tests and a blackstart test performed in Sweden some years ago.

Two main problems associated with the restoration of a power system are the voltage and frequency control. The voltage control includes the energizing of long transmission lines and the reactive capability available as generators, reactive resources in reactors, capacitors, SVC:s etc. The frequency control is associated with the system inertia, turbine governors and their control systems and the frequency dependency of loads [1, 2]. The power consumption of a load that has been disconnected for a time is not the same when it is reconnected. For industrial load it was demonstrated that the power consumption is lower after a disturbance as compared to the pre contingency situation. It then increases to a stationary level after some minutes or even days. Residential load, however, seemed to have a power consumption that was higher after an outage.

By using a power system simulator [1, 3] simulations were performed in order to study the frequency response and voltage behaviour in the Swedish power system. As can be expected when a large load is connected the frequency declines slower when there is a large system inertia. The simulations also demonstrate that the frequency in the system was substantially affected by the chosen operating mode of the hydro turbine governors (different settings for proportional regulation, permanent droop and time constants).

For shunt reactors a hunting phenomenon was sometimes observed after energizing long unloaded transmission lines [1, 4], see 2.2. As almost all shunt reactors in the Swedish system had the same settings of time delays and voltage levels for automatic connection and disconnection the hunting phenomenon may diffuse into the system and incorporate several reactors. By altering the settings it was shown that the hunting phenomenon could be eliminated or reduced.

An important conclusion of the first part of the study was the obvious lack of data/analysis on the load recovery after a disturbance. It was therefore decided to make a further study of cold load pick-up.

1.2 Motivation

A major breakdown of a power system is a contingency that is rare but nevertheless occurs. In order to reduce the economical and social consequences for the population and the power suppliers it is important to restore power as fast and as secure as possible. One of the factors which then must be taken into account is the cold load pick-up. Connection of a load that is several times the rated power gives a larger frequency drop, may give an overloading of lines and transformers and in some cases a situation where the system load demand is higher than the system production capacity. Overloading of lines and transformers may also appear after forced and planned outages which almost daily are performed at various places in the power system.

Cold load pick-up is also of interest in power systems which use a scheme of rotating load curtailment in case of lack of power or in case of limited transmission capacity in the system. If such a scheme is used it is a prerequisite to understand load behaviour in order to be able to tune the scheme properly. A bad tuning or no tuning at all may give an overshoot in the power consumption which can result in a breakdown or severe consequences for the power system.

Some industries, especially processing industries, consume much electricity and therefore it is interesting to study their behaviour after outages. The interest in industrial load behaviour has increased during the last years due to the deregulation of the electricity market which has taken place in several countries.

1.3 Outline of the thesis

This thesis consists of a summarizing part followed by a number of papers either published or submitted for publication. The summarizing part describes the background and motivation of the project in chapter 1. Chapter 2 gives a short introduction to the area of power system restoration, analyses the phenomenon of cold load pick-up and summarizes the literature in this area. Chapter 3 presents an overview of the papers presented in chapter A-E, including results and comments. In chapter 4 general conclusions are given and in chapter 5 suggestions for future work are proposed. At the end of the summarizing part the references of the first five chapter are listed.

Chapter 2 Power System Restoration

A major breakdown of a power system is a contingency which seldom occurs. Following such an outage it is important to restore the power system as fast, smooth and secure as it is possible in order to limit the economical and social consequences. To be able to do this it is necessary to have a good knowledge of how a power system operates during a restoration phase, i.e. a good understanding of the restoration plan, of the active and reactive power resources and of the load behaviour in order to be able to keep the voltage and frequency within acceptable limits.

The literature covers a variety of aspects in the area of power system restoration and especially the IEEE power system restoration group has produced a number of interesting papers [5-16]. Topics are the restoration process [6, 10, 17-19], restoration strategies [6, 17-23], voltage and frequency control [6, 8, 15, 21, 24], blackstarting of stations [5, 18, 20], restart of cold and hot units [6, 7, 9, 10, 14], island operation [1, 6, 22, 23], planning and training for power system restoration [10, 12, 13, 16-18, 20, 23], load behaviour [15, 20, 22, 25-37], expert systems [10, 13, 38] and a variety of problems associated with the restoration [7, 10, 11, 14, 18, 23, 39].

2.1 Restoration strategies

The literature deals with two major strategies for power system restoration following a blackout: the build-up strategy and the build-down strategy [6, 17-20, 22]. These different approaches are used depending on factors as the size of the interrupted area, the possibility to receive assistance from interconnecting systems, the amount of blackstart capability in the system and the type of production in the system.

The build-up strategy is most commonly used. It is usually selected for predominantly thermal systems and often applied when a system has experienced a total blackout and when it is not possible to receive assistance through tie lines from neighbouring systems. After an assessment of the system status has been made the restoration process starts simultaneously in several different subsystems. At least one unit with blackstart capability must be available in each subsystem and units equipped with frequency and voltage regulation must be present. It is also beneficial if there is a balance between the production capacity and the consumption in the area. After blackstarting a unit emergency power is supplied to the stations without blackstart capability in order to make it possible for these units to start up and be connected to the system. Loads are then connected and new units are started. As a next step the subsystems are synchronized. When most of the subsystems are synchronized and there is enough absorbing reactive capacity in the system the breakers of the tie lines to the neighbouring systems can be closed.

The build-down strategy is mostly used in small systems without long high voltage lines, in hydro based systems with good reactive absorbing capacity and for systems which have a concentration of the load in one area. The strategy may also be used when there is a partial blackout or when power can be supplied through tie lines from neighbouring areas. After that an assessment of the status of circuit breakers and the power plant conditions has been made, plants with blackstart capability are started. Lines to other stations are then connected and more units are started. The first priority in the build-down strategy is to reenergize the bulk power network. In contrast to the build-up strategy most of the load is reconnected after a large part of the transmission system is restored. In Sweden the build-down strategy is used in case of a blackout.

2.2 Restoration problems

As the power systems of today are extremely seldom exposed to a disturbance this is a problem in itself since the personnel in control centres and production units have little or no experience at all in handling a system blackout [12]. During the restoration there are many abnormal situations that must be dealt with and equipment may operate in an unexpected way and cause problems [11, 17]. In those Swedish stations equipped with blackstart capability there is often a diesel generator which initially starts and supplies emergency power to the rest of the station [1]. If there is something wrong with this diesel generator such as no diesel, badly adjusted relays etc. the entire restoration may be delayed substantially.

When the main unit is started, lines to other stations are to be energized and new units are started up. When energizing lines it is important to make sure that there is enough reactive resources in the system in order to be able to consume the reactive production from the lightly loaded transmission lines. For that purpose (capacity in) generators, Static Var Compensators or shunt reactors are necessary. The risk for over-voltage can also be reduced by disconnecting shunt capacitors, connecting loads with a lagging power factor, by increasing the circulating currents and reactive losses in parallel transformers, avoiding the energizing of parallel lines and by having a low voltage on transmission lines [7, 8, 15, 17, 23].

Shunt reactors are normally used when the lines are lightly loaded. In the Swedish power system the shunt reactors (and some of the shunt capacitors) are equipped with automatics connecting the shunt reactor when the voltage is above a specified level and disconnecting the reactor when the voltage is below a certain level [1, 4]. The voltage levels are approximately 390-395 kV for disconnection and 420-425 kV for connection. During a restoration phase the power system will be weaker than normal and at the end of a long unloaded transmission line the voltage will be very high. This will result in a connection of the shunt reactor and the voltage will decrease. In case of a large shunt reactor it may decrease below the level for disconnection of the shunt reactor. This will initiate a hunting phenomenon where the reactor will be connected and disconnected several times, see figure 2.1. The

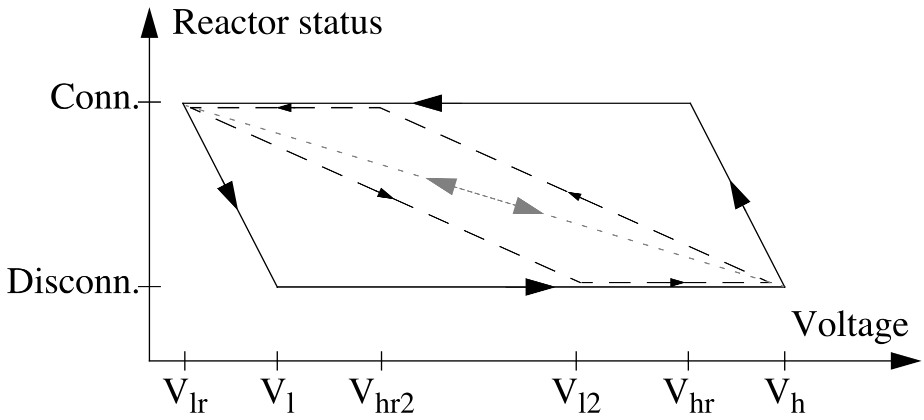

Figure 2.1 Hysteresis curve for the shunt reactor automatics. The solid line is valid when all station lines are connected. Dashed and dotted lines are valid when only one or a few station lines are connected.

hunting of a single reactor may also initiate hunting of other shunt reactors in the system. Especially in systems where the shunt reactors have the same settings of time delays and voltage levels for connection and disconnection this may cause severe problems. In the USA these relays are therefore deactivated until the system is restored.

During restoration a sustained over-voltage will increase the problems of switching transients and harmonic resonance [8, 16, 17, 21, 23]. Harmonics are caused by transformer saturation and for some network configurations resonance will occur (unloaded transformers and low system short-circuit level) leading to damaging over voltages. There could be substantial phase angle differences across line circuit-breakers and closing of such circuit-breakers may damage equipment and may initiate an instability in the system [11, 16, 17].

During the restoration process it will be much more difficult to keep the frequency at a stable level as compared to normal operation since many generators are started and loads are connected. In systems using AGC the mechanism will most likely not be in operation in the initial stage of restoration (the Nordic power system never use AGC). The frequency is affected by the inertia and the static gain in the system, the rate of response of prime movers, the frequency dependency of loads and the size of each load that is connected [23, 24]. A connection (or a disconnection) of a 50 MW load during normal operation is hardly noticeable in a large power system such as the Nordic power system. However, during a restoration a connection of a 50 MW load may affect the frequency considerably. If the frequency declines too much under frequency relays will be activated and loads disconnected (in the USA the under frequency load shedding relays are deactivated during restoration). If a high percentage of the connected load is equipped with under frequency relays this can result in an over frequency [11, 17, 23].

Figure 2.2 shows an example from a field test performed in an island grid [1]. Load corresponding to 10% of the generator power is connected and as can be seen the frequency decreases substantially before the turbine governor has adjusted the water flow and a balance between the electrical and mechanical power is achieved. As load is connected it is also important to consider the cold load pick-up (section 2.4).

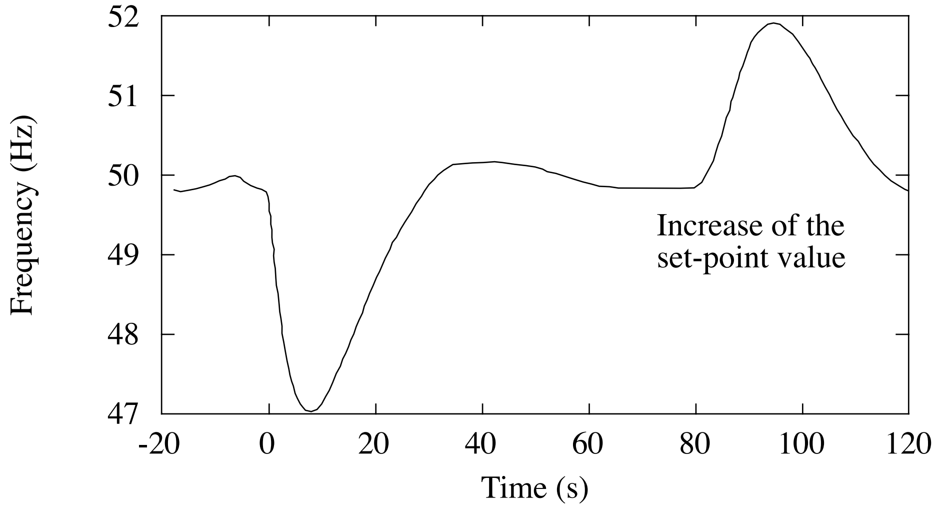

Figure 2.2 Frequency response in the island following a partial reconnection of the load. Hydro power production.

When connecting more load new production units must be started and ramped up. The time it takes to do this varies significantly. For hydro units, gas and diesel turbines the restart time can be as fast as 5 minutes [5, 10] whereas it can take hours to restart steam units [6, 7, 14]. Nuclear power stations take a day or more since they require special procedures [1, 9, 14]. This can be seen in figure 2.3 which shows the power production of the Swedish nuclear power plants after the last blackout in 1983 [1].

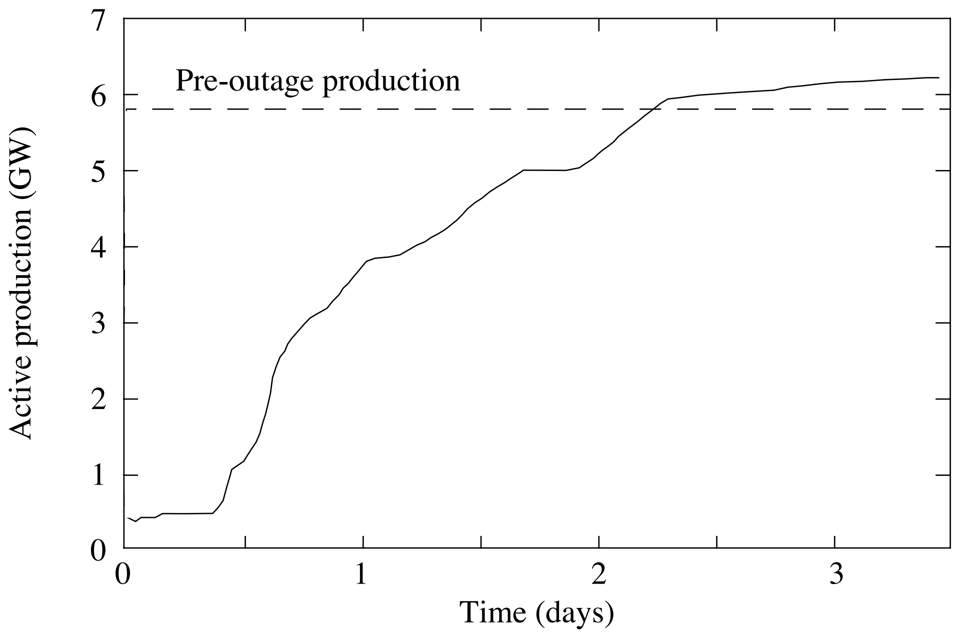

Figure 2.3 Power production from the Swedish nuclear power stations after the last blackout in 1983. Only one plant was in operation during the blackout.

During the restoration it is important for operators to know the system status. There is, however, a risk that the computer systems in the control centres will be overloaded with data due to generator, line and transformer tripping, low voltages, under frequency and under voltage load shedding and other relay actions [14, 17]. Access to a special mode or a special computer system which only takes the most relevant data into account and thereby gives the operator the possibility to get an overview of the system status will significantly increase the success of a restoration.

2.3 Social and economical consequences

In case of a blackout there are substantial economical and social consequences. The industries will suffer from loss of production during the outage time and the time it takes for the restart. In processing industries the restart time is very long and even after a short outage it may take hours or days before the production is back to normal and a proper quality of the product is achieved [1, 48].

Nowadays most of the work in offices is carried out by using computers. During an outage many people may have problem to find useful tasks when they do not have access to the computer. Data may also be lost due to the disturbance and restarting the computer systems after an outage may require some extra work.

Shops and stores operate on the assumption of access to electric power. When power is lost the customers have to be evacuated from the shops and stores and since elevators, escalators and lighting do not function this may be rather complicated. Refrigerating will not function and if the duration is long there is a risk that food is spoiled.

Farms are mostly situated on the countryside and supplied by electricity via overhead lines. Therefore disturbances in the power supply are more common for a farmer as compared to a customer in a city. Many farmers have some sort of backup power which can be used during these contingencies but for those farmers that do not have any backup power there might be a problem with the air conditioning, the water supply or the milking of the cows.

Table 2.1 shows the result of an interruption cost study performed in Sweden in 1994 [40]. In [41-43] similar investigations can be found from other countries. It can be seen that the interruption cost increases with the outage duration and that some industry branches are very sensitive to disturbances.

Table 2.1 Outage cost for different consumer categories. 1 US $≈8 SEK

Category	Outage cost SEK/kW			
	2 min.	1 hour	4 hours	8 hours
Mining industry	2.90	6.0	21.6	34.4
Food industry	4.8	180	394	542
Textile industry	90.5	122	241	410
Timber and wood industry	12.7	35.5	114	210
Pulp and Paper industry	7.7	10	16.9	28
Chemical industry	61.6	87.1	134	243
Iron and steel industry	13.7	19.9	35.5	52.6
Engineering industry	18.7	57.4	180	403
Small industry	9.30	36.4	149	320
Stone and soil industry	4.50	21.0	74.9	215
Commercial sector	13.5	61.9	229	683
Residential sector	0.80	2.40	9.10	25.6

The population will be affected in general since the communication system will break down. Train and underground can come to a stand still anywhere along the railway and evacuating people may be difficult. The battery backup in telecommunication systems will not be able to supply power for a long time and after some hours there is a considerable risk that the telecommunication system will breakdown [1, 6, 14]. If no backup power is available the pressure in water pipes will decrease and there will be no water. There is also a risk that there will be a penetration of slop into the water pipes which may endanger the water supply for many days. If the duration of the outage is long groceries in refrigerators and freezers will be warmed up and this problem will be enhanced since people act irrationally and check the groceries many times. During the winter, long outages will have severe consequences for the heating supply if based on electricity. There will also be problems for other heating systems since electricity is needed for the circulating pump, ignition or control.

2.4 Cold load pick-up

Cold load pick-up is not a new phenomenon. Already in the 1940's and 1950's power companies experienced problems when reclosing circuit breakers [32-34]. The problems were analysed and the conclusion was that when power is restored several household appliances will be restarted and since some of them are motors there will be high starting currents. The solution was to use relays with very inverse characteristics and in some cases sectionalize the system and restore some of the feeders and then wait a time before the others are reconnected.

In the literature of cold load pick-up some authors divide the phenomenon in the following four phases [28, 29, 34]

• Inrush currents to cold lamp filaments and to distribution transformers. The duration is some cycles and the peak can be up to 10 times the pre-disturbance level.

• Motor starting currents. The duration is about 1 second and the peak current can be 6 times the normal value.

• Motor accelerating currents. Duration about 15 seconds.

• In the final phase all inrush currents have died out but due to the loss of diversity among thermostatically controlled loads the power consumption is still above its pre-outage level. Duration is typically about an hour but after an extended outage during cold weather it may take several hours before the heating system returns to normal cycling.

Other authors only divide cold load pick-up in two phases [26, 35, 37]. The first phase then includes the inrush, motor starting and accelerating currents whereas the second phase is due to the loss of diversity among thermostatically controlled loads. In figure 2.4 the power consumption of an incandescent lamp is shown and as can be seen there is initially a peak which after some periods dies out. For a refrigerator and freezer combination the power consumption after two outages is shown in figure 2.5 and for a residential area the power consumption is shown after two outages in figure 2.6. These three figures can be considered to be typical examples of different phases of the cold load pick-up for residential load.

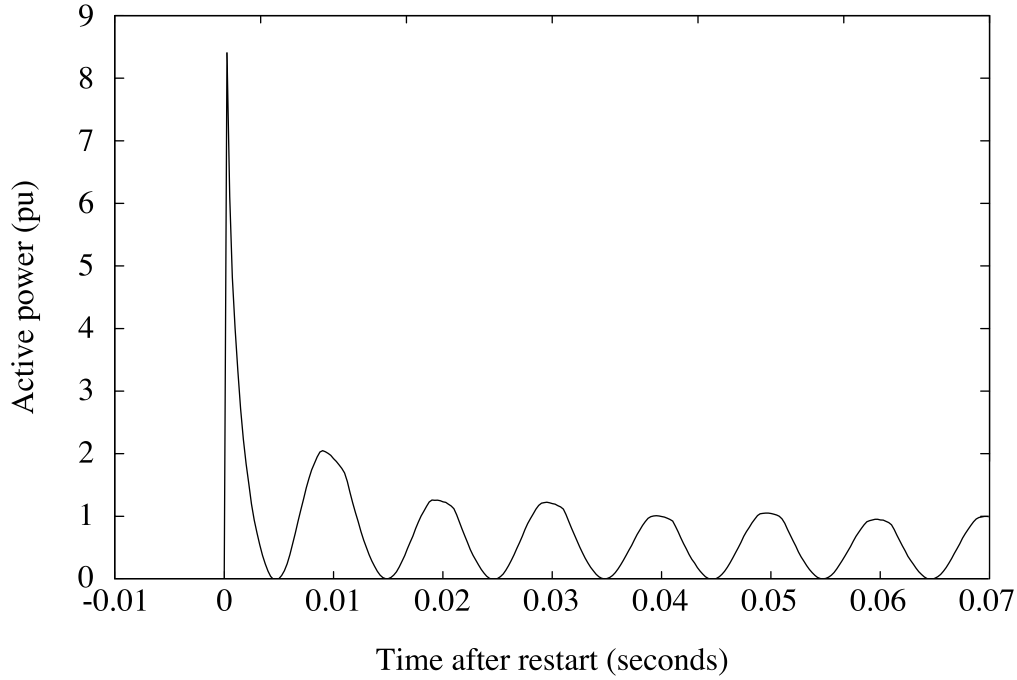

Figure 2.4 The power consumption of an incandescent lamp after an outage.

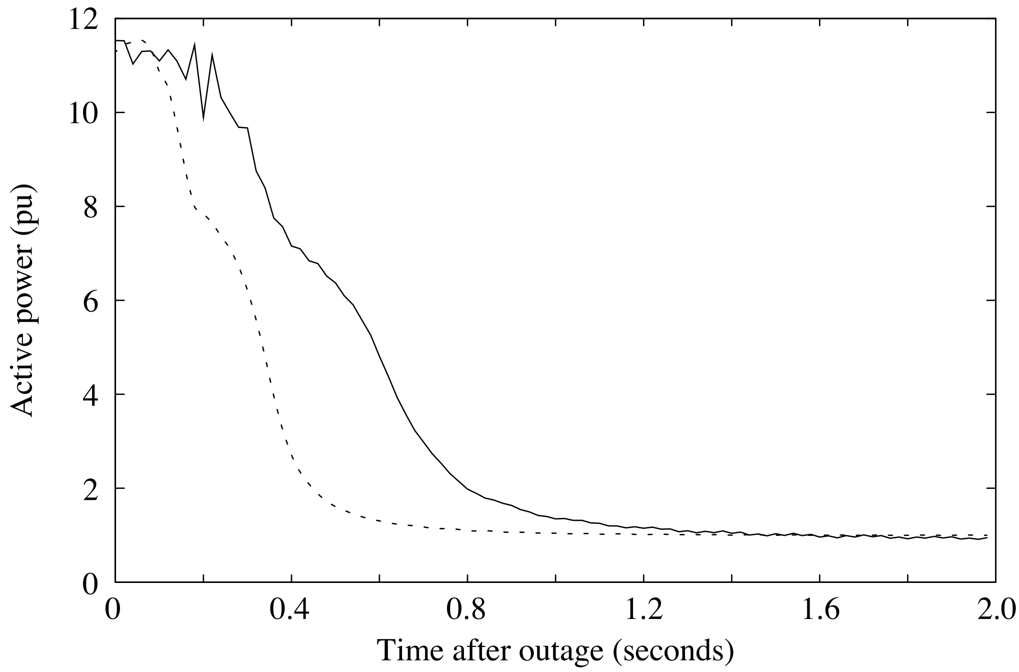

Figure 2.5 The power consumption of a combined refrigerator and freezer after two outages.

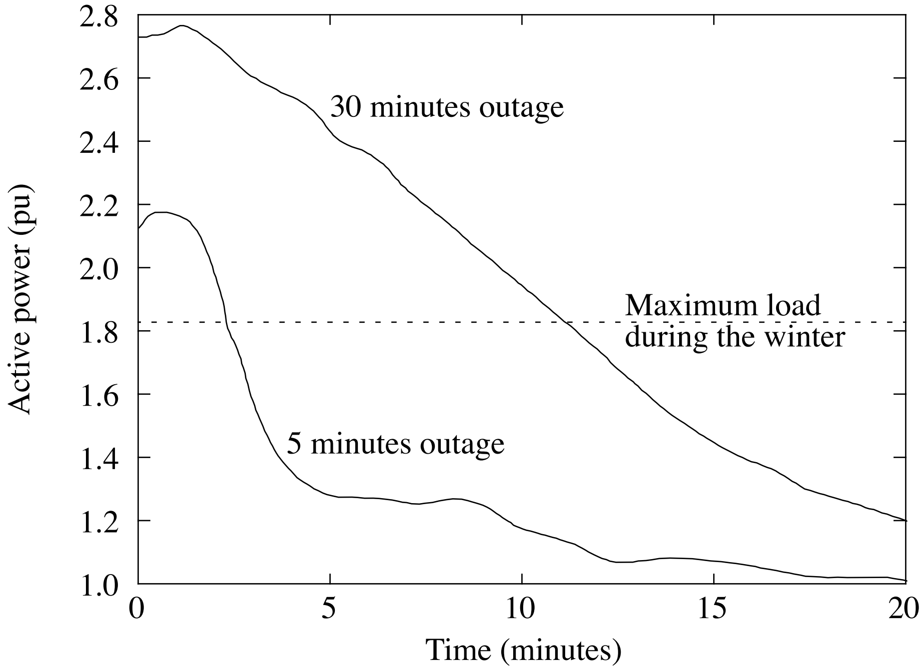

Figure 2.6 Field measurement of the cold load pick-up for 625 houses of which 525 have electric heating. The field study was performed during the night and the outside temperature was +5 °C (base power is the consumption before the interruption).

As previously stated the initial phases of the cold load pick-up were treated in the 1940's and 1950's [32-34]. The loss of diversity was not taken into account at that time. However, the increased use of thermostatically controlled loads such as refrigerators, freezers, water heaters, air conditioners and electric heating resulted in a renewed interest and several papers were written about the problem during the 70's, the 80's and the 90's [15, 25-31, 35-37, 39, 44, 45]. Most of the literature is physically based load modelling [15, 25, 26, 28-30, 36, 37, 44, 45]. A single heating or cooling system governed by a thermostat is then used to obtain the desired indoor temperature. The thermal behaviour is described by first or second order time constants. Figure 2.7 gives an example of a first order model that is used in the literature [25]. G denotes the equivalent thermal conductance (kW/°C) of the building, C the equivalent thermal mass (kWh/°C), Q the heat injected to the building (kW), T_b the inside temperature (°C) and T_{out} the outside temperature (°C).

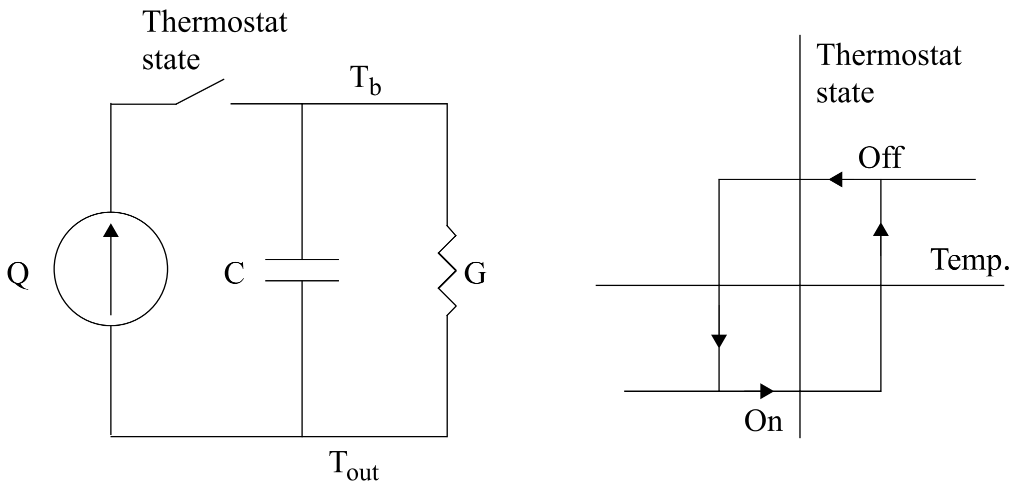

Figure 2.7 A simplified model of a thermostatically controlled heated building.

According to this model the temperature in the building can be written as

$$T_b = T_{bo}e^{-\frac{tG}{C}} + \frac{KQ}{G}\left(1 - e^{-\frac{tG}{C}}\right) + T_{out}\left(1 - e^{-\frac{tG}{C}}\right) \qquad (2.1)$$

where K=0 when the thermostat is in the off state and K=1 when it is in the on state. The aggregate behaviour in a residential area has been found by using means and standard deviations of the model parameters and a Monte Carlo simulation has been performed. In [25, 28, 36, 44] it is also shown that oscillations in the power consumption will be achieved. If the insulation and the thermal mass of the house decrease whereas the duration of the outage and the standard deviation of the thermal model increase the oscillation will be damped out and the load behaviour will be almost like a delayed exponential function.

Some of the thermal load models derived in the literature are based on field measurements of a single house [15, 30, 36] or investigations based on the design of a house [25]. Many of the parameters used in the load models are, however, only examples and are not based on real data.

Field measurements of the cold load pick-up in the residential, the commercial and the industrial sectors are rare due to the difficulties to get permission for such field studies. There are, however, some field measurements available, mostly in residential areas [22, 25, 26, 31, 33-

35, 45, 46]. Often the resolution is low (based on 15 minutes average values of the electric energy consumption) [25, 26] or in some cases the power consumption is only presented for some minutes after the outage [22, 31, 33, 34, 46]. Almost all measurements on residential load show the same behaviour. Initially after an outage the power consumption will be higher or much higher as compared with the pre-outage level. In some cases it will stay on this high level for a time and then decreases to its stationary level. This is in agreement with many of the results obtained when using physically based load modelling.

In [28, 29] the physically based load has been used as a way of modelling the load behaviour in an analytical way and the load can then be described by the equation

$$S(t) = S_U[1 - u(t-T)]u(t) + \\ + [S_D + (S_U - S_D)e^{-\alpha(t-T)}]u(t-T) \tag{2.2}$$

where S_U is the undiversified load, S_D the diversified load, α the rate of decay for the exponential part, T the time at which the exponential function starts and u(t) and u(t-T) Heaviside step unit functions. In [28] and in several other papers different parameter values are used in order to study the aggregate behaviour. There is, however, a lack in presentation of ”typical” parameter values for ”typical” residential areas.

The result of the field measurements in [26, 27] is used for modelling the behaviour according to figure 2.8

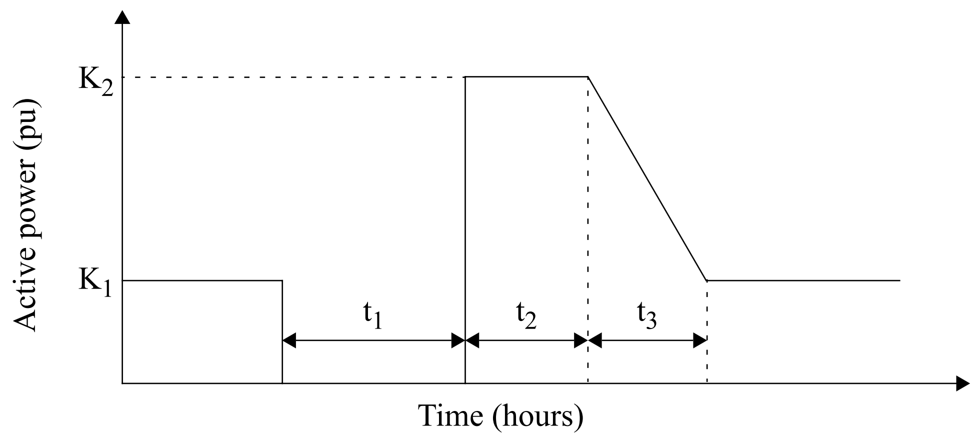

Figure 2.8 Example of a load model for cold load pick-up [26, 27].

where K_1 is the magnitude of the initial load, K_2 the magnitude of the overload, t_1 the duration of the outage, t_2 the duration of the overload and t_3 the duration of the return to normal conditions. Typical values for one hour outages are shown in table 2.2.

Table 2.2 Parameter values for a cold load pick-up model.

Temperature (°C)	t_1 (hours)	t_2 (hours)	t_3 (hours)	K_2/K_1 (pu)
0	1	0.17	0.17	3.70
-20	1	0.34	0.17	2.74
-40	1	0.52	0.33	2.10

Field measurements of commercial and industrial load after an outage have only been found in [31, 48] whereas the behaviour has been discussed in other papers [15, 39]. In [31] measurements from Taiwan are presented when using a scheme of rotating load curtailment. The measurements only show the behaviour some minutes after the outage but from these figures it is possible to see that commercial and industrial load will be lower as compared with the pre-outage consumption. The explanation of this behaviour is that motors and other equipment have been disconnected during the outage and have to be manually restarted when the voltage supply is restored.

Chapter 3 Summary of Publications

This Ph. D thesis covers the work performed during the Ph. D study. In total 12 journal and conference papers [2-4, 47-50, A-E] together with a licentiate thesis [1] have been written. In this thesis five papers on the cold load pick-up are presented [A-E]. These papers can be divided in the two groups residential load and industrial load.

The residential load is treated in three papers where the first paper deals with the cold load pick-up of individual load objects [A], the second one with electric heating [B] and the third paper presents measurements on residential load areas [C]. Industrial load and its behaviour after forced and planned outages is dealt with in two papers where the first one describes pulp and paper industries [D] and the second one analyses other industrial branches [E]. The analysis in the five papers is based on measured data either received from power suppliers, industries or collected by own laboratory and field measurements. The data have then been adapted to represent the dynamic characteristics of the load after an outage. The model parameters are derived using standard (least square) curve fitting methods.

3.1 Paper A, Cold Load Pick-up for Individual Load Objects

This paper presents laboratory measurements of the cold load pick-up for individual load objects. Loads such as refrigerators, freezers, air conditioners, different types of lighting and other household equipment have been investigated. In order to study the effect of the duration of a disturbance the outage time has been varied. It is shown that street lighting and lighting in warehouses, industries and offices, where mercury lamps, high pressure sodium lamps and fluorescent lamps are used, will have a lower power consumption after an outage as compared with the rated power. For fluorescent lighting more than 90% of the rated power consumption returns almost immediately when the voltage supply is restored and the remaining part after some additional minutes. For mercury and high pressure sodium lamps 30-60% of the power consumption returns instantaneously whereas it will take some additional minutes before a stationary level is achieved. For these types of lamps one observes that the illumination improves the first minutes after the power is restored and this is related to the warming up and the pressure increase of the vapour in the lamps which also has an effect of the power consumption.

When studying a large group of cooling equipment such as refrigerators, freezers and air conditioners during normal operation the same fraction of equipment will be in the on state and consuming power. During an outage, however, the temperature inside a cooling equipment will rise and this means that after an outage a larger part or all of the equipment in an area will be in the on state. This is one of the reasons why the power consumption for this load category is higher after an outage as compared with the pre-outage consumption. Another reason is related to the physical behaviour of the cooling equipment. A high temperature inside the cooling equipment will give a higher density of the vapour that is flowing into the compressor. As the compressor compresses a constant volume the mass flow will increase and consequently also the power consumption. When the temperature decreases after a time the power consumption declines. If the duration of the outage is prolonged the load peak and the time it takes for the load to attain a normal level will increase. For a group of refrigerators and freezers it is shown that the power consumption can be modelled with a decreasing exponential function.

For other types of household equipment such as stoves, ovens, washing, drying and dishing machines, radios, TV:s, computers etc. it is more difficult to predict the load behaviour after an outage as the psychological behaviour of people may have a substantial effect on their operation.

3.2 Paper B, The Load Behaviour of Electric Heating following a Disturbance

In some countries a considerable part of the power consumption is related to electric heating. The heating can be electric boilers, electric radiators or heat pumps. In this paper measurements of the cold load pick-up have been performed on several houses where the power supply has been switched off during different time periods. The influence of the outdoor temperature has also been studied since the measurements have been performed during various times of the year.

An electric boiler heats up water which then is transported in pipes to radiators in the rooms. An electric boiler also supplies hot tap water in a house. Usually a boiler consists of several electric elements which are connected and disconnected by a temperature sensor. After a long outage several or all of the heating elements will be connected and this means that the power consumption will be higher or much higher as compared to the pre-outage situation. The increase in power consumption and the time it takes before a stationary level is achieved are strongly dependent on the outdoor temperature and the outage duration. A longer outage and a lower outdoor temperature will increase the peak load and its duration. If the load peak is related to rated power it will be reduced with a decreasing outdoor temperature as the rated power rises with a decreased outdoor temperature.

Another way of heating a house is by using electric radiators. A radiator usually consists of a heating element encased in an envelope. In most cases each radiator is equipped with a thermostat controlling the local temperature and having a cycling period of some minutes. During the measurements performed it has been shown that most of the electric radiators will be in the on state after an outage. This is also valid after relatively short disturbances (30 minutes) and during relatively high outdoor temperature (<+10°C). The time to reach normal power consumption is (as for electric boilers) strongly dependent on the outage duration and the outdoor temperature.

A large group of heat pumps in a residential area will be diversified during normal operation which means that the power consumption of this group will be rather constant. After a disturbance, however, all or almost all of them will be in the on state. The phenomenon of loss of diversity will stand for most of the load peak for this group. In the same way as for cooling equipment the physical behaviour of the equipment will affect the power consumption. This effect varies for different brands but mostly the power consumption starts on a high level and then decreases to a minimum in some minutes. For some brands the power consumption then starts to increase again and this continues until the set point value of the temperature is reached an the heat pump is switched off.

Based on the measurements performed in different houses an aggregation of different electric heating systems has been made. The aggregation was made for different outage durations and outdoor temperatures. The result shows that after an outage it is possible to model the cold load pick-up for electric heating with an initial constant level for some minutes followed by an exponential decrease down to the stationary level.

3.3 Paper C, Cold Load Pick-up of Residential Load

In this paper the cold load pick-up of residential load is investigated. Together with power suppliers in the southwestern part of Sweden measurements have been performed in residential areas. Most of the outages were during the night and the outage time was between half an hour to more than five hours. Since the outages were made during various times of the year also the impact of the outdoor temperature on the cold load pick-up could be studied. An analysis of the load peak and its duration after an outage was made. The load peak and its relation to rated power (CLPUn factor) and to maximum power experienced during the year (CLPUm factor) was investigated. The load peak after the disturbance will also lead to a recovery of some of the energy that was lost during the outage and this has also been analysed. It is shown that the CLPUn factor increases with an increased outdoor temperature whereas the CLPUm factor decreases with an increased outdoor temperature. The time it takes for the load to obtain a stationary level is dependent on the outage duration and the outdoor temperature. An increased outage duration and a decreased outdoor temperature will both increase the recovery time. Also the recovery of energy is affected by the duration and temperature. A higher percentage of the lost energy will be recovered if the duration of the outage is short and the outdoor temperature is high.

Based on the data obtained a load model has been developed. The same load model as previously has been proposed for electric heating was derived, i.e. initially it starts with a constant level for some minutes and then it decreases exponentially to a stationary level. This load model together with suitable parameters have then been used for simulating a system where a scheme of rotating load curtailment is used. The simulations show that it is necessary to tune such a scheme accurately in order to make it work properly. If load is disconnected a short period a larger part of the lost energy will be recovered. This means that more loads must be disconnected at the same time in order to achieve the desired reduction of the total load. If loads are disconnected for a longer period of time the recovered energy will decrease but on the other hand the load peak will increase and this means that there is an increasing risk of overloading lines and transformers. If small loads (on

10 kV level) are used and the rotation is uniformly spread out in time the problem with a load peak will only be valid in the distribution network. However, if each rotation step includes fewer but larger loads the problem with a load peak will also be valid in the transmission system.

3.4 Paper D, Load Recovery in the Pulp and Paper Industry following a Disturbance

Pulp and paper industries are interesting to study from a power system point of view. The plants are characterised by a high electricity consumption and in Sweden there are plants consuming up to 300 MW. Pulp production can either be a mechanical or a chemical production. The chemical production generates much waste products such as barks and lyes including lignin. The waste products are burnt in furnaces producing steam which in its turn is used during the pulp and paper production. As the steam production is higher than the consumption many industries also produce electricity with generators fed by back pressure-turbines.

In this paper measurements of the power consumption after planned and forced outages are presented. The data were obtained from many industries in Sweden. Restarting after a planned outage takes a very long time. In a chemical based pulp industry the most critical process is to start the recovery boilers which stand for most of the steam production. First the boilers have to be slowly pre-heated before black liqour can be added to the process. The production can then start in a small scale and increases after some time. The restart usually takes more than a day but it can take several days before the production is stable and a proper product quality is achieved. The restart time is dependent on whether it is a short planned outage due to a public holiday or if it is a more extensive overhaul taking one or two weeks.

Many industries have the possibility to run parts of their load in island operation. A disturbance in the power supply of such a plant may therefore result either in a total shutdown of the industry or a situation where parts of the load together with the generator(s) succeeds in establishing island operation. The restart of the production following a disturbance varies considerably for these two alternatives. If the change over to island operation is successful it can take half a day to restart whereas it can take a day or more to restart if the entire plant is shutdown.

The power consumption after planned outages has been modelled as a linear increase up to the stationary level. For forced outages a small part of the load returns fast whereas the main part of the power consumption returns after several hours. In that case the power consumption is modelled as an exponential increase having two time constants.

This paper also presents a formula for estimating the outage cost. The formula takes the restart time, outage time and the time it takes to reach a proper product quality into account. An example from an industry consuming 90 MW shows that an outage of half an hour will result in a total economic loss of about 4 MSEK.

The investigation of the pulp and paper industry shows that parts of a production plant can be shutdown almost instantaneously without any major consequences for the operation of the plant. This is due to the buffers stocks which are available between different production stages and enables a continued production. Instead of only having gas turbines for the national disturbance power reserve an alternative would be to partly disconnect loads in pulp and paper industries. Such a system could be cost effective for the company responsible for the national disturbance power reserve but also interesting for pulp and paper industries since they will be economically compensated for the discomfort of such a measure.

3.5 Paper E, Load Recovery in Different Industries following an Outage

This paper deals with the load behaviour after planned and forced outages in many industrial branches. By cooperation with industries and power companies measurements of the load behaviour after outages have been collected. It is shown that the restart procedure after a disturbance will vary considerably for various industry branches. For the engineering industry, sawmills or other small industries the restart after an outage is usually in the order of an hour. For other industries such as refineries and chemical base industries the restart time is usually days.

Generally the restart after a planned interruption takes a longer time as compared with the restart after a forced outage. In the same way as for pulp and paper industries the power consumption after a planned interruption may be modelled as a linear increase up to the stationary level. After a forced outage the load behaviour has been modelled as an exponential increase.

For some types of industries the outage time is very important. In the mining industry an outage longer than half an hour may lead to severe problems since the mine and its equipment will be flooded. In the iron and steel industry an outage of a foundry plant lasting 1-2 hours may have catastrophic consequences as the material will solidify in the furnace. In that case the furnace has to be rebuilt which can take weeks or months. In the chemical industry a long outage may also cause problems. Different gases and liquids get crystallized and this is especially a problem during the winter.

Chapter 4 Conclusions

This thesis have investigated the dynamic behaviour of different types of load used in the residential and industrial sectors following outages. It has then developed mathematical models for such loads, verifying the models against actual field measurements. In the past most power system dynamic studies have been limited to the use of prime mover models and normal load characteristics. This research certainly has demonstrated that to be realistic, the dynamic behaviour of loads should also be considered during these studies.

For all the industries the power consumption will be lower or much lower after an outage. It has been shown that after an outage it will take a long time (several hours or days) for processing industries, such as pulp and paper industries, chemical base industries and refineries to restart. Other branches such as engineering industries, sawmills and small industries recover much faster (usually within an hour).

Residential load has the opposite behaviour as compared with industrial load, i.e after an outage the load is (much) higher than prior to the disturbance and then decreases to its stationary level. Thermostatically controlled loads such as refrigerators, freezers, air conditioners, electric boilers, electric radiators and heat pumps will loose their diversity after an extended outage and all, or almost all of them, will be in the on state when power is restored. This is the major reason of the load increase after an outage but the physical behaviour of cooling equipment will result in an additional load increase.

The results obtained for cooling equipment can be used when studying systems containing much air conditioning load or areas in developing countries where a large part of the load can be related to refrigerators and freezers.

In order to compare measurements performed in different areas and during various outdoor temperatures and outage durations data have been analysed in different ways. The load peak after the outage and its relation to either the rated power (CLPUn factor) or the maximum power experienced during the year (CLPUm factor) has been investigated together with the recovery of energy.

The CLPUm factor is a good indicator of the actual power consumption and can be used when investigating the risk for overloading in a distribution system. The derived residential load models show that the load decreases exponentially. The risk of overloading can then be reduced by sectionalizing the station and connect load in stages, waiting some minutes each time more load is connected.

The CLPUn factor, the recovered energy and the derived industrial and residential load models are of interest when studying the cold load pick-up from the transmission point of view. They can therefore be used when formulating restoration guidelines and when tuning a scheme of rotating load curtailment. Using a scheme of rotating load curtailment incorporating residential load will, however, be problematic as it may lead to an overloading of distribution lines and transformers or in some cases an overloading of the entire power system. If residential load should be used in this scheme it is therefore essential that the personnel have a good knowledge of the cold load pick-up. Another alternative which eliminates this problem is to use industrial load.

Due to the deregulation of the electricity market it is likely in the future that (more) agreements between power suppliers and customers are made which give the power suppliers the possibility to disconnect load when the production capacity is reached or when it is costly to produce the peak power. This may also incorporate the possibility to disconnect load as an alternative to having gas turbines for the disturbance power reserve.

Chapter 5 Future Work

This thesis has investigated the cold load pick-up based on laboratory and field measurements. However, there is still a need for more measurements on residential load during low outdoor temperatures and especially for commercial load which has not been investigated here. With the increase in number an accuracy of load measurements it should be possible in future to develop more accurate load models. As many industries now have installed or are planning to install their own measuring equipment it will also be easier to collect data with a high resolution from these industries in the future.

In the present work the economic loss due to an outage is only investigated for the pulp and paper industries. However, it is important that similar work also is performed for other industrial branches and the residential and commercial sector. An important issue is to cost justify continuity of service, e.g., the trade off between controlled load curtailments and providing generation reserve. Or to cost justify the additional investment and expenditures required to reduce the duration of power system restoration.

The initial title of the project ”Development of Criteria and Strategies for Network Rebuilding following a major Disturbance” still involves many challenges. Investigations on where and how island operation can be run and suggestions and guidelines of how this can be accomplished and improved is an area that needs more consideration, both by more field studies and also by more theoretical analysis. Investigations on island operation should preferably include industries with in-house generation.

The restoration process involves many unusual situations that must be handled by the personnel in control centres. As they in most cases have little or no experience of such work it is important that they are sufficiently trained for such situations. This can be done in role plays and/or by using simulators.

References

[1] Agneholm E., The Restoration Process following a major Breakdown in a Power System, Licentiate thesis, Technical Report No. 230L, Chalmers University of Technology, Sweden 1996.

[2] Agneholm E., le Dous G., Daalder J., The Frequency Dependence of Aggregate MW Loads, International Power Engineering Conference, May 22-24, 1997, Singapore, Proceedings Vol. 1, pp. 414-419.

[3] Agneholm, E., le Dous G., Johansson S., Education and Training by Computational and Laboratory Methods, International Power Engineering Conference, May 22-24, 1997, Singapore, Proceedings Vol. 2, pp. 889-894.

[4] Agneholm, E., Daalder J. E., Shunt Reactor Behaviour during Power System Restoration, International Symposium on Modern Electric Power Systems, September 26-27, 1996, Wroclaw, Poland, Proceedings pp. 154-161.

[5] IEEE Committee Report, Adibi M. M., Milaniscz D. P., Volkmann T. L., Remote Cranking of Steam Electric Stations, IEEE Transactions on Power Systems, Vol. 11, No. 3, August 1996, pp. 1613-1618.

[6] IEEE Committee Report, Adibi M., Clelland P., Fink L., Happ H., Kafka R., Raine J., Scheurer D., Trefny F., Power System Restoration - A Task Force Report, IEEE Transaction on Power Systems, Vol. PWRS-2, No. 2, May 1987, pp. 271-277.

[7] IEEE Committee Report, Adibi M. M., Borkoski J. N., Kafka R. J., Power System Restoration - The Second Task Force Report, IEEE Transaction on Power Systems, Vol. PWRS-2, No. 4, November 1987, pp. 927-933.

[8] IEEE Committee Report, Adibi M. M., Alexander R. W., Avramovic B., Overvoltage Control During Restoration, IEEE Transactions on Power Systems, Vol. 7, No. 4, November 1992, pp. 1464-1470.

[9] IEEE Committee Report, Adibi M. M., Adamski G., Jenkins R., Gill P., Nuclear Plant Requirements during Power System Restoration, IEEE Transactions on Power Systems, Vol. 10, No. 3, August 1995, pp. 1486-1491.

[10] IEEE Committee Report, Adibi M. M., Kafka R. J., Milanicz D. P., Expert System Requirements for Power System Restoration, IEEE Transactions on Power Systems, Vol. 9, No. 3 August 1994, pp. 1592-1600.

[11] IEEE Committee Report, Adibi M. M., Milanicz D. P., Protective System Issues during Restoration, IEEE Transaction on Power Systems, Vol. 10, No. 3, August 1995, pp. 1492-1497.

[12] IEEE Committee Report, Adibi M. M. et al., Bulk Power System Restoration Training Techniques, IEEE Transaction on Power Systems, Vol. 8, No. 1, February 1993, pp. 191-197.

[13] IEEE Committee Report, Adibi M. M., Fink L. H., Giri J., Kirschen D. S., Shahidehpour S. M., Zaborszky J., New Approaches in Power System Restoration, IEEE Transaction on Power Systems, Vol. 7, No. 4, November 1992, pp. 1428-1434.

[14] IEEE Committee Report, Adibi M. M., Fink L. H., Andrews C. J., Arsanjani F., Lanier M. W., Miller J. M., Volkmann T. A., Wrubel J., Special Considerations in Power System Restoration, IEEE Transactions on Power Systems, Vol. 7, No. 4, November 1992, pp. 1419-1427.

[15] IEEE Committee Report, Special Consideration in Power System Restoration - The Second Working Group Report, paper 93 WM 202-2, presented at IEEE 1993 WPM, Columbos, Ohio, January 31-February 5, 1993.

[16] IEEE Committee Report, Adibi M. M., Borkoski J. N., Kafka R. J., Analytical Tool Requirements for Power System Restoration, IEEE Transactions on Power Systems, Vol. 9, No. 3, August 1994, pp. 1582-1591.

[17] Adibi M. M., Fink L. H., Power System Restoration Planning, IEEE Transaction on Power Systems, Vol. 9, No. 1, February 1994, pp. 22-28.

[18] CIGRE TF 38.02.02, Modelling and Simulation of Black Start and Restoration of Electric Power Systems, Electra No. 147, April 1993, pp. 21-42.

[19] Ancona J. J., A Framework for Power System Restoration following a Major Power Failure, IEEE Transaction on Power Systems, Vol. 10, No. 3, August 1995, pp. 1480-1485.

[20] Delfino B., Denegri G. B., Bonini E. C., Marconato R., Scarpellini P., Black-start and Restoration of a Part of the Italian HV Network: Modelling and Simulation of a Field Test, IEEE Transactions on Power Systems, Vol. 11, No. 3, August 1996, pp. 1371-1379.

[21] Morin G., Service Restoration following a Major Failure on the Hydro-Quebec Power System, IEEE Transaction on Power Delivery, Vol. PWRD-2, No. 2, April 1987, pp. 454-462.

[22] Selosse P., Testud G., Nicolas J., Martin M., Strategy of 400 kV Regional Frameworks to Restore the French Network after a Blackout, CIGRE Report 39-104, Paris, France, August 30-September 5, 1998.

[23] Adibi M. M., Kafka R. J., Power System Restoration Issues, IEEE Computer Applications in Power, April 1991, pp. 19-24.

[24] Adibi M. M., Borkoski J. N., Kafka R. J., Volkmann T. L., Frequency Response of Prime Movers during Restoration, PE-412-PWRS-0-06-1998, recommended and approved for publication in the IEEE Transactions on Power Systems.

[25] Nehrir M. H., Dolan P. S., Gerez V., Jameson W. J., Development and Validation of a Physically-Based Computer Model for Predicting Winter Electric Heating Loads, IEEE Transactions on Power Systems, Vol. 10, No. 1, February 1995, pp. 266-272.

[26] Wilde R. L., Effects of Cold Load Pickup at the Distribution Substation Transformer, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-104, No. 3, March 1985, pp. 704-710.

[27] Aubin J., Bergeron R., Morin R., Distribution Transformer Overloading Capability under Cold-Load Pickup Conditions, IEEE Transactions on Power Delivery, Vol. 5, No. 4, November 1990, pp. 1883-1891.

[28] Ucak C., Restoration of Distribution Systems following Extended Outages, Ph. D. thesis, Kansas State University, USA, 1994.

[29] Lang W. W., Cold Load Pick Up: The Electrical Space Heating Component, Ph. D. thesis, University of Missouri-Rolla, USA, 1980.

[30] McDonald J. E., Bruning A. M., Mahieu W. R., Cold Load Pickup, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-98, No. 4, July/August 1979, pp. 1384-1386.

[31] Leou R. C., Gaing Z. L., Lu C. N., Chang B. S., Cheng C. L., Distribution System Feeder Cold Load Pickup Model, Electric Power Systems Research, Vol. 36, 1996, pp. 163-168.

[32] Ramsauer O., A New Approach to Cold Load Restoration, Electrical World, October 6, 1952, pp. 101-103.

[33] Audlin L. J., Pratt M. H., McConnel A. J., New Relay Assures Feeder Resumption After Outage Part 2, Electrical World, September 24, 1949, pp. 95-98.

[34] Hartay C. E., Couy C. J., Diversity a New Problem in Feeder Pickup, Electric Light and Power, October 1952, pp. 142-146.

[35] Mirza O. H., Usage of CLPU Curve to Deal with the Cold Load Pickup Problem, IEEE Transactions on Power Delivery, Vol. 12, No. 2, April 1997, pp. 660-667.

[36] Ihara S., Schweppe F. C., Physically Based Modelling of Cold Load Pickup, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-100, No. 9, September 1981, 4142-4150.

[37] Mortensen R. E., Haggerty K. P., Dynamics of Heating and Cooling Loads: Models, Simulation, and Actual Utility Data, IEEE Transactions on Power Systems, Vol. 5, No. 1, February 1990, pp. 243-249.

[38] CIGRE TF 38.06.04, A Survey of Expert Systems for Power System Restoration, Electra No. 150, October 1993, pp. 87-105.

[39] IEEE Committee Report, Strang W. M. et al., Distribution Line Protection Practices, Industry Survey Results, IEEE Power System Relaying Committee Report, IEEE Transactions on Power Delivery, Vol. 10, No. 1, January 1995, pp. 176-186.

[40] Avbrottskostnader för elkunder, Svenska elverksföreningen 1994 (In Swedish).

[41] Willis K. G., Garrod G. D., Electricity Supply Reliability, Energy Policy, Vol. 25, No. 1, 1997, pp. 97-103.

[42] Sullivan M. L., Vardell T., Johnson M., Power Interruption Costs to Industrial and Commercial Consumers of Electricty, IEEE Transaction on Industry Applications, Vol. 33, No. 6, November/December 1997, pp. 1448-1457.

[43] Wacker G., Tollefson G., Billinton R., A Canadian Cost of Interruption Study, IEEE/NTUA Athens Power Tech. Conference: Planning, Operation and Control of Today's Electric Power Systems, Athens, Greece, September 5-8, 1993, pp. 861-865.

[44] Chong C-Y, Statistical Synthesis of Physically Based Load Models with Applications to Cold Load Pickup, IEEE Transaction on Power Apparatus and Systems, Vol. PAS-103, No. 7, July 1984, pp. 1621-1628.

[45] Law J., Elliott L., Minford D., Storms M., Measured and Predicted Cold Load Pick Up and Feeder Parameter Determination Using the Harmonic Model Algorithm, IEEE Transaction on Power Systems, Vol. 10, No. 4, November 1994, pp. 1756-1763.

[46] Mariani E., Mastroianni F., Romano V., Field Experiences in Reenergization of Electrical Networks from Thermal and Hydro Units, IEEE Transactions on Apparatus and Systems, Vol. PAS-103, No. 7, July 1984, pp. 1707-1713.

[47] Agneholm E., Daalder J., Cold Load Pick-Up, International Power Engineering Conference, May 22-24, 1997, Singapore, Proceedings Vol. 1, pp. 403-408.

[48] Agneholm, E., Daalder J. E., Cold Load Pick-up for Different Types of Industries, International Symposium on Modern Electric Power Systems, September 26-27, 1996, Wroclaw, Poland, Proceedings pp. 148-153.

[49] Agneholm E., Daalder J. E., Fendin H., Ingelsson B., Restoration of the Swedish Bulk Power Transmission System following a major Disturbance. International Symposium on Electric Power Engineering, Stockholm, Sweden, 1995, Proceedings Information and Control Systems, pp. 240-245.

[50] Agneholm E., Daalder J., Cold Load Pick-up after an Outage, accepted for presentation at the 13th Power System Computation Conference, PSCC'99, Trondheim, Norway, June 28-July 2nd, 1999.