The Use of Computers for Controlling Electricity Flows in Sweden, 1950–1980

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Abstract. An important application of computers from the 1950s and onwards has been for designing and operating complex infrastructural systems like air traffic, telephony, railways, and electricity. This paper tells the story about how computers from the 1950s and onwards became an important tool for designing and operating the Swedish power grid. It describes two phases of this development. In the 1950s and 1960s, computers were used for making complicated *calculations* for designing power grids in a reliable way and optimizing the use of the different power plants. In a second phase starting in the late 1960s, computer systems were developed for *real time monitoring* supporting human control of the power grid. The paper analyzes by whom and for what purposes computers became tools for controlling electricity flows. In the conclusion, it also discusses the wider implications of computers for the development of the Swedish power system.

Keywords: Control, computers, efficiency, power systems, stability, Sweden TIDAS.

1 The Challenge of Stability

In Sweden, many of the large rivers and hydropower resources are located in the northern part of the country, while most of the population and industries are located in the south. Starting in the 1930s, long power lines were built to enable transmission of power from the north to the south and these lines became the backbone in a national power grid. However, the power grid also entailed a new kind of vulnerability due to the increasing complexity and the tight coupling between all the components. This meant that a disturbance in one part of the country could spread quickly to other parts of the system [1].

Power engineers were particularly concerned about so-called power oscillations: a sudden accident in a power plant or transformer station could cause major oscillations in the transmission lines. Such oscillations could affect transformers and power plants far away. In the mid 1920s, a young engineer at ASEA, Ivar Herlitz, studied this problem and developed a mathematical method for designing stable and robust transmission lines. His method was a forerunner of what became the new discipline of control theory in the 1950s. It was used when the first Swedish 220 kV power lines from the north of Sweden were designed in the early 1930s [2, 3].

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As the number of power lines increased, so did the complexity of the power system and Herlitz' method led to ever-larger calculations. In the early 1950s, the State Power Board, or Vattenfall as it is usually called, built a special laboratory where a physical model of the Swedish power system was constructed. (Vattenfall was responsible for operating the national grid.) It was a so-called network analyzer similar to the one built by Vannevar Bush at MIT in the 1930s [4]. This network analyzer made it possible for engineers at Vattenfall's Planning Division to simulate different kinds of disturbances in the grid. It was also possible to test different configurations of future power lines, but the preparation of these configurations was very time consuming.

When the computer BESK became available in the mid-1950s, Åke Ölwegård at Vattenfall's Planning Division developed a model for simulating the Swedish power system on BESK. Because of the limited capacity of BESK, the model was simplified – for example, it had only six power stations – yet, it behaved similar to the more "correct" model of the network analyzer. Moreover, the big advantage was that the parameters could change notably faster between subsequent simulations. A simulation that would take two days to prepare on the network analyzer could take only fifteen minutes to prepare with BESK [5].

When more powerful computers became available in the early 1960s, Ölwegård and his colleagues at Vattenfall's Planning Division developed a more comprehensive computer model of the Swedish power system called Dynamic Stability (DYN STAB). Vattenfall was able to make simulations at night on a big IBM 7090 computer, owned by the Swedish Defense Research Institute, FOA, until Vattenfall bought a computer of its own in the mid-1960s [5].

In the 1960s and 1970s, the complexity of the Swedish power system grew substantially, first because many power lines were built to neighboring countries and a Nordic grid emerged, secondly because huge nuclear power plants were built and taken into operation. These changes altered the system properties of the power system in a fundamental way [6]. The computer models described above were very important tools for planning and designing this expanding system in such a way that it would be robust and stable. These computer models were also used to make instructions for the personnel operating the grid. In particular, safety margins were calculated so the grid would be able to withstand a major disturbance, for example, the loss of a transformer or a high-tension line, without affecting consumers.

2 The Challenge of Efficiency

In all large-scale power systems, an important challenge is to use the various power plants in an efficient way. In the 1960s, twelve large power producers dominated the Swedish power industry. The largest one of these was Vattenfall, which owned almost 50 percent of all generating capacity. Each of the twelve power companies had a regional monopoly in some part of Sweden where it sold power to local utilities and industries [7].

Until the 1960s, Swedish electricity supply was predominantly based on hydropower, and yearly variations in precipitation and winter temperature influenced the availability of power in different parts of the country. The risk of shortage could be diminished by building storage dams and thermal power plants for backup, but such facilities were expensive and managers of the power companies realized that they had much to gain from mutual cooperation. If companies with a surplus of water in their dams could sell power to those with a shortage and if many companies could use thermal backup plants jointly, it could substantially lower the overall cost for reserve capacity.

Nonetheless, the selling and buying of power called for common rules for calculating the marginal cost for power. For thermal power, the marginal cost was rather easy to calculate. The dominant cost element was the cost of fuel. However, the marginal cost of hydropower was much more complicated to estimate. It had to take into account not only the operation costs, which were minimal, but also the risks for having to use thermal power later on or to ration electricity. These risks were dependent on the water level in the up-stream water reservoirs and the expected precipitation. In the 1950s, two engineers at the Sydkraft power company, Sven Stage and Yngve Larsson, developed a rather sophisticated mathematical theory for such calculations. The latter developed a computer program for these calculations that ran on BESK [8]. Ölwegård recalls that he and Larsson met each other sometimes while running their respective programs at night on BESK [5]!

Vattenfall developed a similar method for calculating marginal costs and there was a certain tug of war between the two methods. Nonetheless, a power pool agreement was reached in 1965 between the twelve largest power companies. This power exchange made possible a coordinated and very efficient use of almost all Swedish power plants and storage dams. In parallel, with negotiations about a power pool in Sweden, there were also efforts to establish power exchange among the Nordic countries. In 1963, a new Nordic organization for power cooperation, Nordel, was established. A few years later, the same principles for power exchange as in Sweden were adopted for the entire Nordic region.

3 Monitoring the Grid with Telephones

In the 1930s, Vattenfall established a central control room for the daily operation of their power plants and transmission lines. In 1947, the Swedish parliament made Vattenfall responsible for the management and operation of the entire Swedish power grid and Vattenfall's central control room became the national control center. The physical location of the control room was in Vattenfall's office in central Stockholm until 1962, when it moved to Vattenfall's new huge office building in Råcksta, a suburb of Stockholm.

The most important measuring instrument in the control room was a frequency gauge. The frequency should be as close to 50 Hz as possible and if it started deviating from 50 Hz this was a sign that *something* un-normal and unwanted was happening, but not what it was. Therefore, the key technical tool in the control center was the telephone. If an incident happened somewhere in the power system the engineers in the national control center were informed of what had happened through a telephone call from colleagues out in the country. When the control room engineers had made an analysis of the situation and what actions were needed, they phoned back and gave orders. Thus, when major disturbances occurred there was a very intensive calling [9]!

Normally two people worked in the central control room. One of them was responsible for the safe *operations* of the national power system. He gave orders to control centers around the country to start or stop power plants so that the total generation closely followed the total consumption. This was a prerequisite for keeping the frequency close to 50 Hz. He also checked that safety margins remained at all critical nodes in the grid. The other engineer was responsible for the economic *optimization* of the power system. His task was to make assessments and forecasts of which power plants in the country were most economical to use at each point in time and in the coming day and week, and to make offers to other companies to buy or sell certain quantities of power. He also registered all sale and buy deals so that they could settle them afterwards. Similar deals were also made with power producers in Denmark, Finland, and Norway. Both engineers used simple rule of thumb calculations for most of their decisions and these rules were based on the computer models mentioned above [9].

Daily control of the power system in Sweden was thus remarkably "low-tech" until the mid-1970s. This was possible because the power system – designed with the help of computer programs – was as stable and robust as possible. In addition, strict safety margins were established with these programs. Furthermore, many small disturbances were handled automatically without any human interference at all. For example, if the frequency dropped below a certain level, some designated hydro power plants or gas turbines would start automatically within seconds.

The engineers in the national control center had a large responsibility and mistakes could – literally – have far-reaching consequences. For example, Gunnar Ålfors, who worked many years in the control room, had a nightmare experience in the early 1970s when he was new on this job in the control center. To compensate for a burnt electronic component in a transformer station near Östersund, he ordered the closing down of a transmission line to Karlstad, but by mistake he said the wrong name and another power line between Karlstad and Gothenburg was closed down. This led to a power loss and oscillations in the southern part of Norway and within a few seconds a power line to Oslo broke down and the whole city became black [9]!

4 Monitoring the Grid with Computers

Another much larger blackout had occurred some years earlier abroad. On 9 November 1965, a fault occurred at the Niagara power station and within ten minutes, overloads had cascaded through the interconnected power grid in the northeastern states of the US and the whole of Ontario in Canada. Approximately twenty-five million people were left without electricity for up to twelve hours. That an electric blackout could have this magnitude was a shock to the public, politicians, and engineers alike.

The shock waves went far beyond the North American continent, and alarmed the engineers responsible for the operation of the Swedish power grid. In the mid-1960s, Sweden was connected with transmission links to the neighboring Nordic countries. This meant that up to fifteen million people in the four Nordic countries could be affected if a major blackout would occur in Sweden. Moreover, in the coming decade new big nuclear power plants would come into operation, which would make the Nordic power system even more complex.

Shortly after the big American blackout, Lars Gustafsson, the head of the Operations Division at Vattenfall, initiated an investigation concerning measures to avoid similar events in the Swedish grid. The investigators recommended the procurement of a computer system for monitoring the grid. The system could *collect* current data from power plants and transformer stations from all over the country approximately every ten seconds, *process* these data and present them in a lucid and usable way, and make *calculations* to determine the optimal mode of operation of the power system a week ahead. The system was called *T*otally *I*ntegrated *D*ata *A*cquisition *S*ystem (TIDAS), a name that tells something of the ambitions [10].

In the spring of 1971, a call for tenders was sent out to about twenty potential bidders, and the incoming tenders were carefully assessed half a year later. In 1972, the Swedish firm ASEA, which had been a major supplier of equipment to Vattenfall for half a century, was chosen as the main supplier for the new computer system. To be more precise, a new subsidiary called ASEA-LME Automation was responsible for the project. They established this subsidiary the previous year and recruited engineers from both ASEA and the telephone manufacturer LM Ericsson. ASEA engaged TRW Control, as a subcontractor for the computer part of the project. TRW was a company with headquarters in Houston, Texas and specialized in control engineering for the space and automobile industry, but also with some experience from the power industry. It was absolutely crucial for Vattenfall that the computer system would be reliable; therefore, Vattenfall participated actively in the development of TIDAS. Vattenfall engineers went both to Houston and to Västerås and Ludvika in order to follow the development work and to make sure that the computer system would be well adapted to the Swedish grid.

ASEA-LME Automation was responsible for the transmission part of the system. At an early stage some of the engineers read an article in an IEEE publication on "Adaptive Routing Techniques for Computer Communication Networks" describing the new ARPA network, [11]. The ASEA engineers found this promising and decided to embark on this road. However, the communication network for TIDAS was more complex than the ARPA network and contained more nodes. According to Torsten Cegrell, one of the ASEA engineers, they redesigned the ARPA network to achieve a robust and stable system, and according to him, this new design was important for the further development of the internet [12].

In parallel, TRW Control worked on the data processing part of the project, called TIDAS-D. TRW in turn worked closely with Xerox Data Systems. Two Sigma 9 computers from Xerox were chosen as the hardware for the system. A whole series of very extensive tests had taken place before Vattenfall would accept the new system. When the Houston team had completed its work, the computers and all the peripherals were flown to Stockholm in a chartered Boeing 747 Jumbo Jet [12].

In Stockholm, the computer part was merged with the communication networks from ASEA. The combined TIDAS system was very carefully tested and personnel from the central control room as well as the regional control centers were thoroughly trained before Vattenfall dared make the decision to take it into operation. The TIDAS system went into service at 7 AM on 7 February 1977 and it worked [13].

The cost to develop and install the entire TIDAS system amounted to about a hundred million SEK. It was unique in several respects. In particular, the data transmission part was very advanced at the time. Data accumulated at 150 power plants and transformer stations and about a thousand measurements went to the national control center via sixteen nodes with eight-second intervals using packet switching technology. ASEA managed to develop a robust and stable routing mechanism with very high reliability. The data processing part was also advanced. It consisted of two identical Sigma 9 computers, one of which was in continual operation while the other was on stand-by and used for the training of personnel. The computer linked a number of workstations and key boards. The operators could look at no less than eight-hundred different graphs of the current situation in the power system. In addition, the computer automatically made statistical compilations of all incoming data to serve as a basis for planning the operations for the coming week [10].

TIDAS was not an automatic control system, but a monitoring system that assisted control room engineers. Through TIDAS, they had a much better overview of the entire power system and they did not have to rely on rule of thumb calculations any more. This led to a more efficient use of the generating (and storage) capacity in the power system. The estimated gain equaled a medium sized hydropower station. Moreover, the national power grid could operate with more precise safety margins than before. This meant that the system operated at a higher capacity, as the earlier rules of thumb had been more conservative in compensating for the insufficient overview. One could compare this with a driver in a new car with better breaks and controls who is tempted to drive faster than in his or her old car. We should note, however, that TIDAS did not prevent some major blackouts; for example, a major blackout occurred 27 December 1983 when all of southern Sweden lost power.

5 Conclusion

Let me finally briefly discuss the wider implications of computers for the development of the Swedish power system at large. This paper has described how computers from the 1950s and onwards became an important tool for designing and operating the Swedish power grid. It has outlined two phases of this development. In the 1950s and 1960s, computers were used for making complicated *calculations* for designing power grids in a robust and reliable way, and for optimizing the use of the different power plants. In a second phase starting in the late 1960s, computer systems were developed for *real time monitoring* supporting human control of the power grid. We should note that Vattenfall did not dare introduce the kind of automatic process control systems that for example IBM had developed for industrial purposes [14]. Instead, they developed a system "with a man in the loop"; that is, one in which a human operator made the crucial decisions but continuously received data about all components in the system. The responsibility for controlling electricity flows thus remained in human hands and minds.

The introduction of TIDAS meant rather big changes in the daily operation of the Swedish power grid, and this spurred certain resistance. One kind of resistance came from inside Vattenfall, because TIDAS altered the tasks and responsibilities for different divisions and groups as well as for individual people. Another resistance came from other power companies as TIDAS gave Vattenfall a much better overview of the entire Swedish power system than any other entity. However, the advocates of TIDAS overcame these different kinds of resistance.

TIDAS was only one part of the computerization of the Swedish power industry. In parallel, also other parts of the industry were computerized, including the local distribution and the billing of customers. This meant that the ability to monitor and control electricity flows from the power plants all the way to the final consumers increased rather dramatically, and this in turn was a technical prerequisite for the deregulation of the power industry that occurred in Sweden during the 1990s. This is arguably the most profound effect of TIDAS and other computer systems in the industry. However, no one anticipated this effect when computerization was initiated in the late 1960s.

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References

1. Perrow, C.: Normal Accidents. Princeton University Press, Princeton (1984)
2. Herlitz, I.: The Dynamic Stability of Long Transmission Lines. Royal Institute of Technology, Stockholm (1928)
3. Fridlund, M.: Den gemensamma utvecklingen. Symposion, Eslöv (1999)
4. Mindell, D.: Between Human and Machine. Johns Hopkins University Press, Baltimore (2002)
5. Interview with Åke Ölwegård by the author
6. The Swedish State Power Board, The Swedish 380 kV System. Stockholm (1960)
7. Högselius, P., Kaijser, A.: När folkhemselen blev internationell: Avregleringen i historiskt perspektiv. SNS förlag, Stockholm (2007)
8. Larsson, Y.: Autobiography, http://www.tekniskamuseet.se/
9. Interview with Gunnar Ålfors by the author, who worked in the control room ca 1970–2000
10. The Vattenfall archive in Arninge has a special file on the TIDAS project
11. Fultz, G., Kleinrock, L.: Adaptive Routing Techniques for Store-and-Forward Computer-Communication Networks. In: Proceedings of the IEEE International Conference on Communications on Conference Record, Montreal, Canada, pp. 39-1–39-8 (June 1971)
12. Cegrell, T.: A Routing Procedure for the TIDAS Message-Switching Network. IEEE Transaction on Communications 23(6) (1975)
13. Vedin, B.-A.: Technology, Tumbling Walls of. Institute for Management of Innovation and Technology, Göteborg (1990)
14. Åström, K.J.: Oral history interview by Per Lundin October 3, 2007 National Museum of Science and Technology, Stockholm, Från matematikmaskin till IT, interview 3