Intelligent systems and their application to power systems

Gustavo Arroyo-Figueroa

Instituto de Investigaciones Eléctricas, Gerencia de Tecnologías de la Información
Reforma 113, Col. Palmira, 62490, Cuernavaca, Morelos, México
garroyo@iie.org.mx

(Paper received on September 06, 2010, accepted on October 15, 2010)

Abstract. The purpose of this paper is to show the relevance of Artificial Intelligence (AI) techniques to support the operation of Electric Utilities. Under the current demanding conditions of operation and the introduction of the smart grids the power system operators require support systems to operate successfully. Intelligent systems have demonstrated their ability to integrate, analyze and process information (incorrect, imprecise or with uncertain) properly and timely. Intelligent systems can be used to support the operation of power systems, such as planning (operation, design, etc), monitoring (fault diagnosis, alarm processing, etc), control (normal and emergency control), information security and quality (unauthorized access, reability), and others. The paper shows some of the efforts developed at the Instituto de Investigaciones Electricas for monitoring, diagnosis, control, planning, learning, and system analisys of power systems.

Keywords: diagnosis, planning, control, data mining, intelligent systems, power systems.

1 Introduction

The growing needs for supplying vast amounts of electricity energy with high quality have necessitated more sophisticated approaches to power systems. A power system can be described by a great variety of processes with multiples state variables, events and disturbances. The processes include power generation, transmission, distribution and energy control.

The above requirements have so far been achieved partly by great efforts of experience operators and partly by automated systems. The computer and information technology have been extensively used in power systems operation. Distributed control systems (DCS) and management information systems (MIS) have been playing an important role to show the plant status.

Despite the remarkable progress in the extent and quality of the automation technology, much still depends on the judgement of human experts, that is "experienced operators" capable of making intuitive and yet efficient decisions on the basis of the comprehensive knowledge of the operation conditions. In non-routine operations such as equipment failures and extreme operation (start up phase, changes

Special Issue in Advances in Artificial Intelligence and Applications
Research in Computing Science 51, 2010, pp. 77-86

in the load, emergencies, natural disasters etc.), human operators have to rely on their own experience.

The more complicated power system operating problems such as monitoring and control under emergency conditions, security and stability enhancement, load forecast, optimization, training, etc, demands new computer integrated technologies that reduce operator's working burden by providing operation support systems. Artificial Intelligence (AI) has been considered promising to deal with problems that require both, human expertise and heuristic combined.

The potential use of AI techniques in power systems lies in that while there are so many tasks which are difficult to be handled by the conventional approaches, intelligent systems have capabilities of dealing with such problems very efficiently an precisely. The strong motivation for introducing intelligent systems into power systems comes from the following factors which are likely to occur in the alert state, during disturbances, while load shedding, handling alarms, and during system restoration: mass data, complexity of network structure, combinatorial nature of solutions, incomplete information, data conflict [Tamura, 1987]. In power systems, the state variables change over time in response to events and disturbances, as well as the transition of time itself. In these processes, a variable (or signal) exceeding its specified range of normal operation is considered an event, and a sequence of events that have the same underlying cause are considered as a disturbance. During disturbances or faults, the operator must determine the best recovery action according to the type and sequence of the signals received.

The goal of this paper is to show an overview on intelligent system applications to power systems. To identify the potential areas to which intelligent systems can support the operation of power systems. To classify the AI techniques used for power systems. Finally an analysis of the future applications of intelligent systems on power systems is presented.

2 Potential applications in power systems.

The AI applications to power systems can be classificated by the process application [Tamura, 1987]. Some of the potential applications and expected improvement include:

Contingency Analysis – a more robust selection of cases to be studied, an evaluation of the solution accuracy of using a steady state algorithm, and a more concise presentation of the solution results.

Alarm Processing – a more concise statement of the problem and to provide a priority to the importance of each alarm.

State Estimation – a more complete method of bad data and of blazed data identification, an alternative method of tap estimation, and to adapt the bus section load models of conforming and of nonconforming loads.

External Model Estimation – the buses which should be reduced, the pseudo measurements which are the best indication of the state of other power systems, and an analysis of the present state of the total power system.

Remedial Action – the controls which should be considered, the control order (generation or tap position changes), and the controls which should be used after the next contingency.

Automatic Generation Control – selection of regulation participation factors for units under control, unit not responding logic, and automatic tuning of unit and system parameters.

Economic Dispatch – generation of energy conversion curves, selection of curves, more complete handling of forbidden unit operating regions and valve points.

Unit Commitment – decision of when to re-execute the algorithm, selection of algorithm (e.g., full, sequential or truncated dynamic programming), selection of constraints to be enforced, and models to be used.

Short Term Load Forecast – selection of base curve, selection of weather variables, selection of model parameters (e.g., degree of differencing, number of components in a Multiple Autoregressive Moving Average process), and estimation of the impact of exogenous variables (e.g., Wielson ratings).

Interchange Evaluation -- selection of possible schedules to be evaluated, pricing of potential schedules, and execution of an evaluation algorithm.

Dispatcher's Optimal Power Flow – selection of control variables to use, selection of control variable ordering, and selection of constraints to enforce.

Contingency Analysis – selection of contingencies to be evaluated, selection of equipment loadings to be checked, selection of contingency cases for remedial action.

System Restoration – selection of cranking path(s), selection of load restoration, selection of generation restarting schedule.

Contingency Relay Arming – selection of relays to be armed or disarmed, selection of key system parameters (equipment, status) to be used as triggers, selection of equipment(s) to be removed for each contingency.

Energy Cost Reconstruction – selection of costing algorithm, selection of unit(s) to be used for costing, selection of transaction schedules to be used for costing, and selection of transmission loss model for costing.

Load Shedding – selection of distribution feeders to open which will most likely remedy system overload or voltage violation.

Load Management – selection of load curtailment strategy based upon expected load and weather trends.

Trouble Call Analysis – faster identification of outaged equipment based upon equipment reliability, weather conditions and load demand in addition to customer complaints.

3 Intelligent systems applications for power systems

In the development of Artificial Intelligence systems for power systems it is important to solve the problem of coupling numerical methods (used in engineering) with heuristic manipulation (used in intelligent systems) [Arroyo et al., 1994]. In this work the functions of the intelligent systems applied to power systems are classificated into six categories, mainly, monitoring, control, planning, learning or training, system analysis and others.

3.1 Monitoring.

Monitoring is the main application of intelligent systems on power systems. Monitoring categories include real time monitoring of sequential events, alarm processing, identification of the cause of alarms, fault diagnosis, identification of process behavior, detection of malfunctions in protective systems, event prediction among others.

3.2 Control.

The operation of the power systems must be optimal considering higher production profits, safer operation, pollution regulations and life extension. Additionally the power system should meet the demanding conditions of the electrical systems. To meet these requirements, the computer and information technology have been extensively used through DCS and MIS. However, these DCS and MIS use a classic PID Controller, which does not have a good performance to meet the demanding conditions of the power systems, especially in non-normal operation. The complexity of these problems and difficulties to implement PID conventional controllers motivate to research the use of advanced control techniques such as intelligent controllers.

3.3 Planning.

A planning system provides a set of suggested actions or operation recommendations to optimize safety and process. The planning system automatically chooses and organizes actions, by anticipating their expected outcomes, to achieve some preset goals. Every time a recommendation is executed, the process state process changes into a new state which directly maps to another recommendation. The sequential concatenation of these recommendations produces an optimal action plan that manages the process behaviour to achieve a desired goal state.

3.4 Learning and training.

Education applications of intelligent systems on power systems is being intensively studied and applied. Training of operators is an important problem faced by power systems: updating knowledge and skills. The process of learning how to control, maintain and diagnose in power systems takes years of practice and training. For safety efficiency reasons it is not recommend training operators on real equipment. The training requirements of power systems ask for powerful interfaces, a more efficient and better adaptive training, using artificial intelligence techniques, adaptive interfaces, simulations tools, learning objects based on multimedia and virtual reality components.

3.5 System analysis.

Systems analysis applications of intelligent systems on power systems include static and dynamic analysis. In the area of static analysis, the applications can be for load flow engine, decision of remedial measures MVar instability index, security assessment, system model validation and user interface of stability program.

4 IIE Intelligent systems applications for support Power Systems

The Electrical Research Institute of Mexico (IIE) has been working in various fields related to operational support of power systems using AI.

Some works have been made about the monitoring, control and planning in power plants. The architecture f an intelligent system for power plant, shown in Figure 1, is integrated by four modules: signal validation systems, monitoring, diagnostic and control [Arroyo et al., 1994].

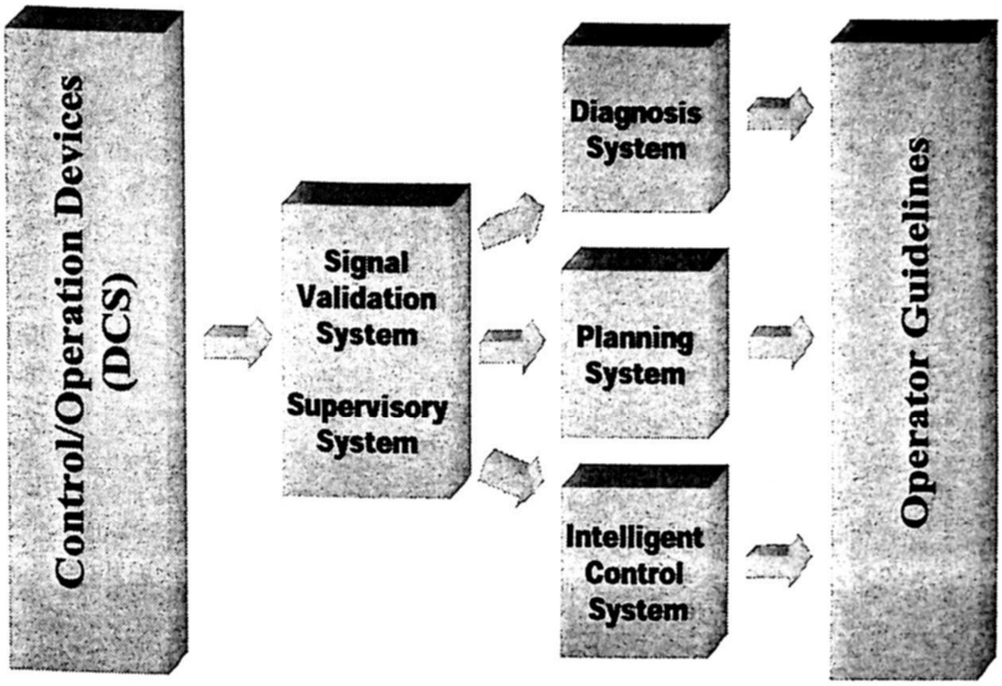

Figure 1. *Architecture of intelligent system for power plants.*

4.1 Signal validation system.

In power systems operation, monitoring and control are complex tasks which require a great number of sensor, alarms and displays. The operator depends on the input data that he receives. The process control assumes that the input data are a set of valid and reliable data. However, due to common cause failures in power plants, the input data may be faulty, and thus, the data may require validation routines. IIE conducted a probabilistic model for validation of sensors [Ibarguengoytia, 2006]. The model represents relationships between variables using Bayesian Networks and utilized probabilistic propagation to estimate the expected values of variables.

4.2 Monitoring system.

Many monitoring systems have been developed at the IIE for support the operation of power systems. All developed with the aim of showing the status of the process, some of them contain intelligent mechanisms that show operating guidelines in accordance with the existing process conditions.

4.3 Diagnostic system.

The objective of a diagnosis system is to determinate the main cause of a fault or disturbance. The analysis starts when an event (signal out range) is detected by the monitoring systems. The IIE has been working in different approaches for the diagnosis of fault or disturbances based on the following requirements: early detection and diagnosis, isolability, robustness, multiple faults, explanation facility, adaptability, reasonable storage, and computational requirements.

A network of events is a probabilistic network designed to deal uncertainty and time [Arroyo et al., 2005]. In the network each node represents an event or state change and an arc corresponds to a causal-temporal relationship between the events. The inference mechanism consists in the propagation of evidences through the net using a probabilistic inference mechanism. When an event is detected, the inference mechanism updates the marginal probabilities of each node (variable) of the network. This probabilities are used to determinate the most probable disturbance and the most probable event occurrence. An empirical evaluation is presented for a subsystem of power plant, in which this approach is used for fault diagnosis and event prediction with good results. The model can be used for the diagnosis of cascade of anomalies arising with certain delays; this situation is typical when an emergency or abnormal operation is presented. This approach can be extended to other power systems.

Other examples of diagnosis systems developed at the IIE are: on-line diagnosis of gas turbines using probabilistic and qualitative reasoning [Flores, 2005]; on-line diagnosis system using influence diagrams for gas turbine systems [Morales, 2004].

4.4 Control system.

The aim of this system is to control the critical parameters of the power system. The control objective of the power systems steam is to adjust the variables as quickly as possible in response to changes in the electrical utility. The objective is to design a controller that guarantees stable and efficient power system operation under a wide range of abnormal conditions.

The IIE has been working in several approaches for process control. Special interest has been developed in power control and power plant control, given the complexity of the applications. For example the temperature control of the steam generator.

Temperature control is considered to be the most demanding control loop of the steam-generation process. The control of the steam temperature is performed by two methods: to change the spray water in the steam flow, mainly before the super-heater; and to change the burner slope in the furnace, mainly in the reheated. The main objective of this manipulation is to keep constant the steam temperature when a change in load is made. Dynamic Matrix Controller (DMC) and Fuzzy Logic Controller (FLC) were applied to regulate superheated and reheated steam temperature [Sanchez, 2004]. The results show that the FLC controller has a better performance than advanced model-based controller, such as DMC or a conventional PID controller. The main benefits are the reduction of the overshoot and the tighter regulation of the steam temperatures. FLC controllers can achieve good result for complex nonlinear processes with dynamic variation or with long delay times.

Other recent approaches are fuzzy logic controller [Garduño, 2000], neuro-fuzzy controller [Ruiz-Hernandez, 2002], knowledge based controller [Lara, 2002].

4.5 Planning system.

The IIE has been working in an approach for planning system based on markov decision process methodology [Reyes, 2009] wich provide a powerful framework for solving sequential decision problems under uncertainty. Given a problem specification, the objective is to obtain the optimal policy getting the plant to a state under optimal operation. The planning system was tested in the steam generation subsystem of a thermal power plant simulator. The idea is to obtain a control strategy that considers stochastic commands on the valves and, according to an experience-based preference function, maximizes the security in the drum, and/or the power generation. The experiments, developed in a power plant simulator, demonstrated that probabilistic automated planning can solve complex problems successfully.

5 IIE Intelligent systems applications for Learning and Training.

IIE has been working in intelligent systems for learning and training of operators of power systems. An example is the intelligent environment for training; this intelligent environment is composed of four main components (see Figure 2): the domain knowledge module, the tutor, the operator model, and the learning management system (LMS) [Arroyo, 2006].

The first module contains the knowledge of the domain in form of learning objects and concept structure maps. The tutor module is the component that generates the sequence of learning objects to be presented to operator in form of course. Taking as a basis the concept map, the pedagogical component and the operator model, the training course planner generates a specific course for each operator. The operator model is used to adapt the intelligent environment (IE) to each specific operator. The operator model is divided into three subcomponents: cognitive component, operator profile and affective component [Hernandez, 2007 and 2008]. Finally, the LMS controls the interactions with the operator, including the dialogue and the screen layout. The main purpose of an LMS is to present to the operator the learning materials in the most effective way. In contrast with a classical ITS, the IE builds a course based on cognitive, affective and pedagogical aspects. The intelligent tutor module will be a dynamic course generating system interacting with the operator model to produce training material specific to each operator.

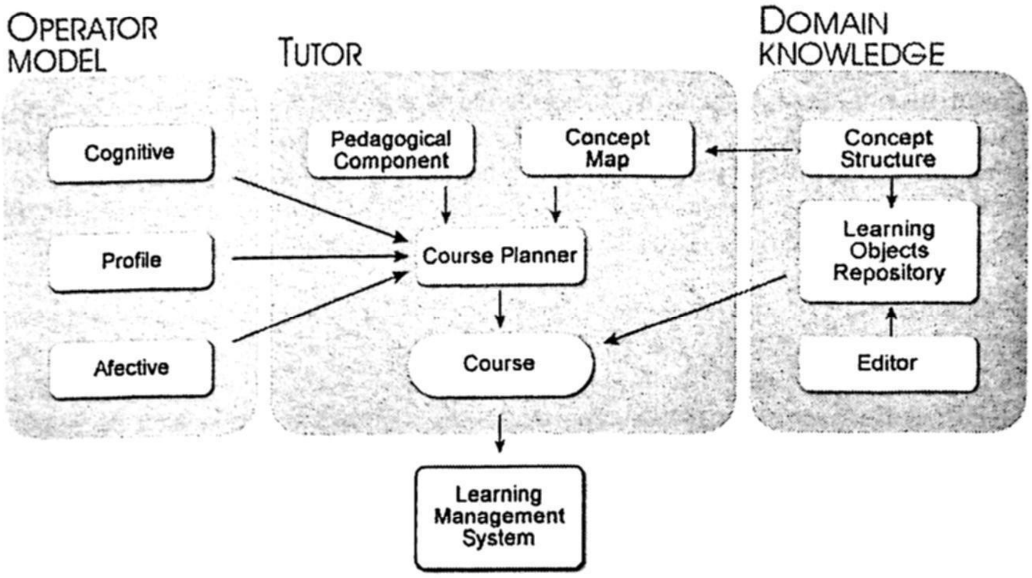

***Figure 2.** Architecture of the intelligent environment*

6 IIE Intelligent systems applications for system analysis.

IIE has been working in system analysis to obtain the knowledge that resides in the databases operational, technical and administrative. One example is the knowledge discovery and data mining. Data mining is applied to huge volumes of historical data mainly with the expectation of finding knowledge, or in other words, when it is sought to determine trends or behavior patterns that permit to improve the current procedures of marketing, production, operation, maintenance, or others. Using different knowledge discovery approaches, the IIE has worked in several power systems domains [Mejia, 2008].

The first domain is about electric generator diagnosis using expert systems plus a novel neural network paradigm. The second one is related to flashover forecasting in high-voltage insulators, where we proposed several tools to approach this problem. The third case is about obtaining expert knowledge, applying and comparing well known data mining techniques to hydroelectric and thermoelectric utilities databases. The last case approaches a pattern recognition problem to detect potential electric illicit users, where we proposed and realized a pre-processing feature selection method.

The table 1 presents the successful and bad practices, and comment about possible solutions for future work that we think it have to be done to maximizing the usefulness of the data mining approach.

Table 1. Our experiences and recommendations

Approach used	Advantage	Our contribution	Drawback	Possible solution
Expert System	Representation of human-expert knowledge in a natural way.	Electric Generator Failure Diagnosis Expert System.	Complex elicitation process.	Develop more sophisticated and computer aided elicitation tools.
Neural Network	Captures knowledge from numeric data.	PHAF II Paradigm.	It needs manual tuning. Discovered knowledge is in a black box.	Develop tools for dynamical tuning and to extract knowledge from neural inter-connections.
Induction Tree	Captures and shows knowledge from nominal data in an explicit way.	Tools that combine the ID3 algorithm and the Nearest Neighbor Case-Based Reasoning method .	It needs previous data discretization. Obtained results are not very precise.	Develop tools for automatic and efficient data discretization. Improve output thru post-processing-visualization tools.
Data Mining	Discovers and shows hidden knowledge from data.	Tool conceptualization that combine and integrate a user interface, pre-processing, mining and post-processing facilities.	It needs an integration of the pre-processing, processing and post-processing phases.	Construct a integrated system with: data quality process, final user easy of interpret knowledge representation and visualization tools.
Feature Selection	Detects relevant attributes and reduces problem size.	Metrics and algorithms considering inter-dependencies among attributes.	There is no infallible method.	Research for metrics that evaluate attribute relevance (numeric and nominal data at once) in an effective way.
Bayesian Network	Models that deal with uncertainty and time.	A temporal event bayesian network model (TEBN).	Difficult to scale it for real fossil fuel power plants.	Developing a network structure automatic learning mechanism based on process data.

7 Summary and future work

This paper shows how intelligent systems can support the operation (monitoring, control, and planning) the learning and training and the analysis of power systems, The application of intelligent systems to power systems is an hot area of research. The application of intelligent systems in power system is adequate and useful for solving some problems for which traditional programming techniques are not able to provide good solutions.

References

1. Arroyo-Figueroa G., Villavicencio A.: Intelligent System to Improve heat rate in fossil power plants. In Proceedings of IFAC Symposium on Artificial Intelligence in Real-Time Control, Valencia Spain, (1994), 365-371.
2. Arroyo-Figueroa G., Sucar L. E., Temporal Bayesian networks of events for diagnosis and prediction in dynamic domains, Applied Intelligence, Springer Science, Volumen 23, 2005, pp. 77-86.
3. Arroyo-Figueroa G., Hernández Y., L. E. Sucar, Intelligent environment for training of power systems operators, Knowledge Based and Intelligent Information and Engineering Systems KES, *Lecture Notes in Computer Science 4251*, Springer-Verlag, 2006, pp. 943-950.
4. Flores Zenon, Ibarguengoytia Pablo H., and Morales Eduardo Morales. On-line diagnosis of gas turbines using probabilistic and qualitative reasoning. In *13th Intl. Conf.on Intelligent Systems Application to Power Systems, ISAP-2005*, Washington, D.C., U.S.A., 2005.
5. Garduño-Ramirez R. and Lee K. Y. Lee, Fuzzy Scheduling Control of a Power Plant, *In Proc. IEEE Power Engineering Society Winter Meeting*, (2000), January.
6. Hernández, Y., G. Arroyo-Figueroa and L.E. Sucar, Intelligent Tutoring System with Affective Behavior. In Proceedings of 6th Mexican International Conference on Artificial Intelligence, MICAI 2007, IEEE CS Press, November 4-10, 2007, Aguascalientes, México.
7. Hernández, Y., E. Sucar and C. Conati, An Affective Behavior Model for Intelligent Tutors, Proceedings of the International Conference on Intelligent Tutoring Systems, ITS 2008, June, 23-27, 2008, Montreal, Canada, pp. 819-821.
8. Ibarguengoytia Pablo H., Vadera Sunil and Sucar L. Enrique, A probabilistic model for information and sensor validation, The computer journal, Vol. 29, No. 1, 2006.
9. Lara Salvador, Garduño Raul, Sanchez Marino, Castelo Luis and Carretero Marco, A Process Knowledge-Based Controller for Maneuverability Improvement of a Nonlinear Industrial Process, Proceedings of the 8th Ibero-American Conference on AI: Advances in Artificial Intelligence, Lecture Notes In Computer Science; Vol. 2527, 2002, pp: 785 – 794.
10. Mejía-Lavalle M., Arroyo-Figueroa G., Morales E., Innovative applications of diagnosis, forecasting, pattern recognition, and knowledge discovery in power systems", IEEE Power & Energy Society General Meeting PES'09, Otawa Canada, Julio 2009, pp. 1-9.
10. Morales Baldramino Morales and Ibarguengoytia Pablo H. On-line diagnosis using infuence diagrams. In L.E. Sucar R. Monroy, G. Arroyo and H. Sossa, editors, *MICAI 2004, LNAI 2313*, Berlin Heidelberg, Springer-Verlag, 2004, pp. 546-554.
11. Reyes Alberto, Sucar L. E., AsistO: A Qualitative MDP-based Recommender System for Power Plant Operations, Special Issue Innovative Applications of Artificial Intelligence, Computacion y Sistemas, 2009.
12. Ruiz Hernandez José A., Suarez Dionisio A., Shemolov C Evgen and Villavicencio A. Predictive Control Based on an Auto-Regressive Neuro-Fuzzy Model Applied to the Steam Generator Startup Process at a Fossil Power Plant, *Advances in Artificial Intelligence, Lectures Notes in Artificial Intelligence 2313*, 2002, pp. 430-439.
13. Sanchez-Lopez A., Arroyo-Figueroa G., and Villavicencio-Ramirez A., Advanced control algorithms for steam temperature regulation of thermal power plants, Electrical Power and Energy Systems, Volume 26, 2004, pp. 779-785.
14. Tamura Y. et al., "An international survey of the present status and the perspective of expert systems on power system analysis and techniques", Report CIGRE working group 38.02.07, Task Force 07 "Expert Systems for power systems analysis and techniques", 1987.