Intelligent On-Line Decision Support Tools For Market Operators

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***Abstract*--- The deregulation of the electric power industry has evolved rapidly and market operators are facing new challenges to resolve issues with system operations and market operations. This paper intends to demonstrate the potential of using intelligent decision support tools to assist market operations. Business rule approach has been selected for system design and development. Domain knowledge of market operations are captured in a common knowledgebase. Several application areas are identified and prototypes have been developed to validate the applicability and feasibility of rule-based technology in market operation environment.**

***Index Terms*---Decision support, deregulation, market operation, electricity market, intelligent system, business rule, system operation, power system.**

I. INTRODUCTION

OVER the past decade, the deregulation of electric power industry has been going through significant changes. Economic forces have been driving the dramatic restructuring of the electric power industry in the United States as well as throughout the world. This has triggered some rapid evolution of electricity market design and power system operations [1]. From an information technology perspective, in addition to using the energy management system (EMS) to maintain the reliability and security of the interconnected power systems a new class of computer system called the market management system (MMS) has emerged to assist operators to manage wholesale electricity markets. Functional requirements rapidly evolve over the past ten years [2,3,4]. Such pace of changes is envisioned to continue for at least another five to ten years. These days, many system operators, market operators and power system engineers are being challenged with rapid changes of operating procedures, tools and complicated job duties for which they might not have adequate background, experiences and training. As a matter of fact, it is very desirable to obtain assistance from intelligent decision support tools that could provide constructive guidance to the market operators during stressful or abnormal operating conditions. This allows the market operators to make sound and timely decisions.

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Applying artificial intelligence (AI) to the operation and planning of electric power systems is not a new thing. Techniques such as rule-based system [5], neural network [6], fuzzy logic [7], decision tree [8], and genetic algorithm [9] had been researched and, in some cases, put into practices to help power system engineers to solve complex power system problems. Rule-based system is a piece of computer software designed to embed knowledge in the form of rules acquired from human experts in a specific domain and imitate the problem-solving behavior of human experts in a logic-reasoning process. Rule-based systems or knowledge-based systems have been successfully applied to power system operations such as alarm processing, dynamic security assessment, power system diagnosis and restoration [10]. In recent years, interest in rule-based intelligent systems was revived. Such revival is mainly due to the advancement in computer technologies. Popularity of applying rule-based technology in other industries such as insurance and banking also pushes the rule-based technology forward, making it more practical and attractive to be applied to the deregulated power industry.

The remainder of this paper is organized as follows. Section II addresses some of the challenges with market operations from both a utility business perspective and an information technology (IT) perspective. Section III conceptually describes the benefits of deploying a rule-based technology in the market operation environment and how rule-based system could assist market operators to make decisions. Several examples of how rule-based decision support systems will be illustrated in Section IV. Conclusions are drawn in Section V.

II. CHALLENGES IN MARKET OPERATIONS

Regional transmission organizations (RTO) and independent system operators (ISO) are responsible for the day-to-day reliable operation of bulk power generation, transmission systems of large geographical areas with an installed capacity ranging from 25-100 GW. In addition to operating the bulk power grid, each RTO/ISO is the administrator of its region's wholesale electricity marketplace comprised of hundreds of market participants. RTOs/ISOs have been designing and implementing innovative methods and solutions for system operations and markets since its earlier days of formation [11,12].

From a utility business perspective, there are significant changes in operation environment that poses challenges to market operators since the beginning of deregulation. As the deregulated market expands and evolves, there are increasing demands for new functionalities. Business processes that govern the daily operations of RTO/ISO's are constantly changing resulting in unavoidable variances in standard operating procedures. A lot of the operating procedures are getting extraordinary complex with inter-related conditions. There are significant risk of impacting system reliability and market efficiency due to non-adherence to the procedures. Moreover, the geographical footprints of some of the RTOs have expanded dramatically for the past few years. All of a sudden, the market operators of those expanded RTOs have to manage control areas and generations that they are not familiar with. Of course, the "graying/greener" effect of the utility workforce just makes the already existing problems even more challenging.

From an IT perspective, the increasing reliance on IT as the basis for operating procedures has led to embedding business process logic in data sets and applications. When business logic is hardwired into application processing, a number of challenges arise including:

- Lack of agility - It is often difficult to locate the business logic that requires change and once it has been identified, the entire application often requires regression testing to ensure that the application operates properly.
- Lack of labor division – It is often challenging, if not impossible, for market operators or power system engineers to maintain business logic embedded within applications. Modifying this logic generally requires IT staff to perform application modification and testing, thus leading to sub-optimal usage of IT resources.
- Lack of transparency – Business logic is currently not easily accessible by market operators or business owners. This often leads to a lack of understanding on the functionalities of the delivered/modified systems by the business owners or operators, thus reducing competitiveness and efficiency.
- Lack of auditability - It is often difficult to track why and what decisions were made at any given time, especially when it could impact the outcome of market clearing prices. In an environment where RTOs/ISOs are subject to ever increasing regulation, including the compliance of the Sarb-Ox Act and the conformance of the standard of SAS70, auditing plays a critical role in ensuring and verifying that the right decision is made based on a given set of inputs.
- Lack of consistency - Business logic reuse is often impossible across applications. As new applications are devised for RTOs/ISOs, certain similar functions tend to be replicated across various applications. This does not contribute to overall system consistency.

With the understanding of the above challenges for the market operators, it is envisioned that some rule-based decision support tools could be devised to assist market operators to make crucial decisions in a competitive environment.

III. Rule-Based Decision Support System

A Rule-Based Decision Support System (RB DSS) could be a viable solution to address the above challenges for market operators (Figure 1). The RB DSS has reached certain level of maturity over the last few years and its potential application to market management systems are worth considering.

The RB DSS allows business owners or market operators to maintain and fine-tune a knowledgebase of rules that impact market application behavior without being over-dependent on IT to modify systems and hence reducing IT related costs. It provides a wide range of intuitive and domain specific interfaces with natural language for rule authoring whilst being managed in a controlled environment. As a result, part of rule authoring responsibility could be accomplished by non-IT staff or business owners. These interfaces also provide transparency to market operators and business owners so that confidence could be built upon their own systems. Rules could typically save in some proprietary central repository which has a built-in mechanism to support integration, auditability, and handles difficult performance and scalability challenges.

By adopting a RB DSS, business agility in terms of speeding-up the time to market and reframing mindsets on the business side of the company will be increased. RB DSS facilitates the rapid propagation of rules changes from a desktop to the deployment system. Once business owners realize that the bottleneck for getting a rule changed is no longer IT related, they will rise to new levels of efficiency.

The RB DSS improves the quality of decision making by capturing certain human expertise in the form of rules in a common knowledgebase. Using an efficient rule engine with a well-developed knowledgebase, a RB DSS could assist operators to make mission-critical decisions consistently in an ever-demanding market operations environment. Figures 2 and 3 illustrate the vision of how the concept of operator's assistant links between human operator and traditional application programs using rule-based technology. The traditional application oriented approach is shown at the top of Figure 2. In the lower part of Figure 2, the domain knowledge of an experienced human operator is captured by the rules in the assistant layer. The assistant layer could provide integrated advisory information to a less experienced human operator to assist him or her to make crucial decisions. As assistance and guidance provided by the assistant layer become mature and robust, the corresponding set of business rules could be executed without human approval or verification. In that case, the assistant layer could further decomposed into an automation layer and an advisory layer as shown in Figure 3. The business rules in automation layer do not require human intervention while the rules in the advisor layer do. Basically, the business rules in the advisor layer will migrate to the automation layer over time.

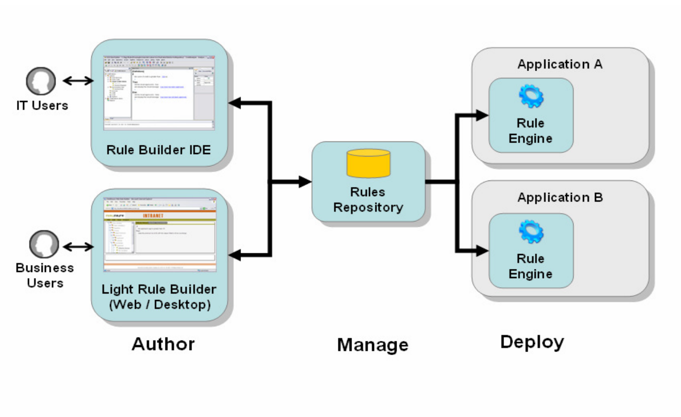


Figure 1. Rule-based decision support system

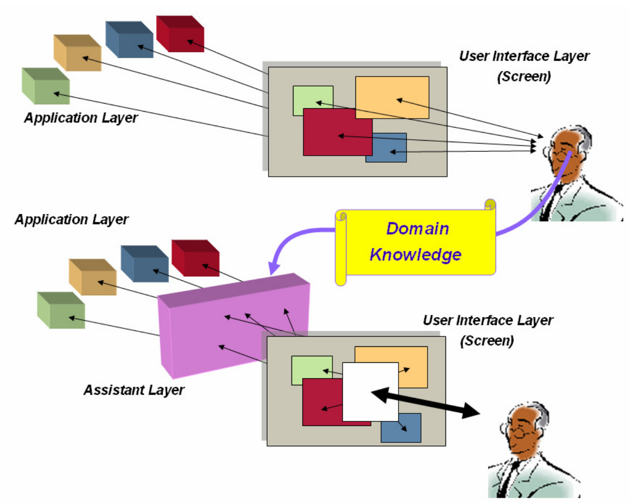


Figure 2. The role of operator's assistant

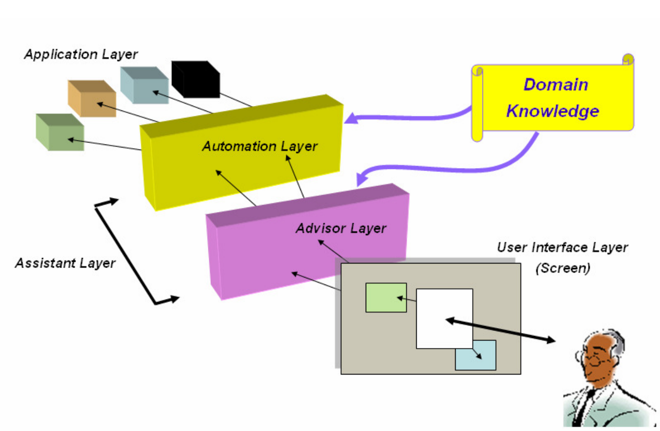


Figure 3. Automation of operator's assistant

The RB DSS taking the role of an Operator's Assistant (OA) could do the following:

- Intelligent link between human operator and application programs to solve operation problems
- OA coordinates application programs
- OA automates certain decision-making
- OA renders trivial data manipulation transparent to users
- OA provides timely and consistent suggestions to operators

THE RB DSS and the concept of OA will be applied to some selected market operation problems in the following sections.

IV. Problem Solving By Rule-Based Decision Support Systems

Market operation has distinctive problem compared to other industrial process operations. The system is interconnected and spread over a wide geographical area. A large number of variables and constraints must be monitored and controlled. Complex system phenomena threaten the stability of operations and could lead to regional catastrophic events. This section describes three practical and diversified examples of applying rule-based technology to solve real-life market operation problems. A prototyped application is developed for each example as a proof-of-concept of applying rule-based technology to a multi-settlement market system of standard market design (SMD). A typical multi-settlement system consists of two markets:

1) Day Ahead Market - schedules resources and determines the locational marginal prices (LMP) for the next 24-hour based on offers to sell and bids to purchase energy from the market participants.
2) Real-time Market - optimizes the clearing of bids for energy to meet real-time system load and reliability requirements are satisfied based on actual system operations. Hourly ex-post LMPs are computed for settlement.

The market management system strongly interacts with market participants and the energy management system. Market participants submit offers and bids into market systems. The MMS runs its market clearing engine to clear the market based on participant-submitted data. The market clearing engine determines market prices and dispatch instructions. Desired dispatch points and generating unit characteristics are sent to the EMS by the MMS. Current power system state and real-time data including transmission constraints are sent to the MMS by the EMS. Market results and system conditions are published back to the market participants. Figure 4 illustrates the high-level functional interactions for market operations.

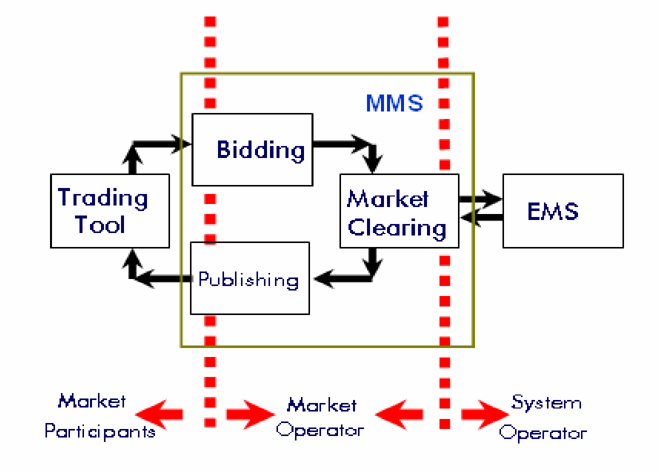


Figure 4. Market operation interaction

A. *Example 1 - Data Validation for Market Systems*

There are high volume of data exchanged between market participants and market operators on a daily basis. The quality and consistency of data are important because bad data could potentially choke the market-clearing applications or impact their performance. In many cases, problematic data could only be identified by in-depth analysis which is very time-consuming. Data need to be corrected and market needs to be rerun. Data from market participants are normally stored in some databases and the data need to be validated against the market rules and validation rules before and after market applications run. For market systems, we categorize validation rules into five different types:

- Parameter Validation – ensures certain parameters to be set correctly.
- Data Integrity Validation – ensures certain basic market metadata are in place and with proper entity relationship.
- Market Operator Input Validation – ensures data from the EMS or entered by the market operators are in place and within reasonable ranges.
- Bid Data Validation – ensures bid data and generating unit characteristics data submitted by the market participants are in place and within reasonable ranges.
- Solution Validation – cross-checks solution data to discover potential solution problems.

Traditionally, all these rules are spread across different applications in different forms. Some of the validation logic is unnecessarily duplicated and are not always consistent with each other. The goal is to centralize as much validation logic as much as possible in one single repository. Using a commercial business rule management system (BRMS), a prototype is developed as a plug-in to an existing market system. This prototype aims at separating the market data from the data validation business rules. BRMS provides a graphical user interface for the business analyst and other non-technical staff to modify business logic and validation rules. This not only improves the transparency of the validation business logic but also allows better labor of division and agility of the overall software development life-cycle for non-IT staff could involve in making those business logic modifications.

This data validation system prototype shows promises to help market operators to identify data problems up-front before the market clearing process has begun and avoids any unnecessary re-clearing of the day-ahead market. This could significantly improve the on-time approval rate for the business process of market clearing.

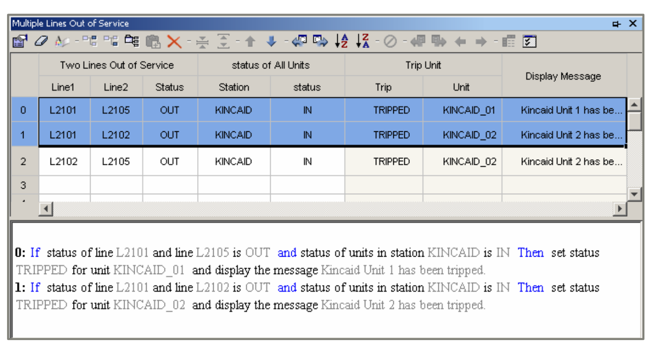
B. *Example 2 - Transmission Operator's Guide Automation*

The increasing complexity in day-to-day operations of power markets and the changing operational procedures for power systems are driving the need of decision support tools to assist transmission operator to make crucial decisions. This is particularly true for RTOs experiencing dramatic geographical expansion and their workforce does not have enough experience to effectively manage the expanded installed capacity and enlarged power grid. One idea is to automate existing transmission operating procedures into rules. Real-time system conditions are scanned by the decision support tools and a RB DSS will provide recommendations of preventive or corrective actions to the transmission operators.

The purpose of this RB DSS is three-fold:

1. Replace the existing processes of manual look-up
2. Transform data into useful information for transmission operators
3. Reduce human errors and their possible exorbitant costs due to such errors.

The prototype automates 18 pages of operating procedures that approximates to about 17 rule packages. A rule package consists of one or more business rules and other elements defining the business logic, such as decision tables and rule flows. Each rule package has approximately 4-10 different rules and may contain nested rule packages. This prototype demonstrates the integration capabilities of rule engine with external real-time data sources. Figure 5 shows some operating procedure business rules in the form of decision table and natural language.


Multiple Lines Out of Service

	Two Lines Out of Service			status of All Units		Trip Unit		Display Message
	Line1	Line2	Status	Station	status	Trip	Unit	
0	L2101	L2105	OUT	KINCAID	IN	TRIPPED	KINCAID_01	Kincaid Unit 1 has be...
1	L2101	L2102	OUT	KINCAID	IN	TRIPPED	KINCAID_02	Kincaid Unit 2 has be...
2	L2102	L2105	OUT	KINCAID	IN	TRIPPED	KINCAID_02	Kincaid Unit 2 has be...
3								

0: If status of line L2101 and line L2105 is OUT and status of units in station KINCAID is IN Then set status TRIPPED for unit KINCAID_01 and display the message Kincaid Unit 1 has been tripped.
1: If status of line L2101 and line L2102 is OUT and status of units in station KINCAID is IN Then set status TRIPPED for unit KINCAID_02 and display the message Kincaid Unit 2 has been tripped.

Figure 5. Decision table and natural language rules

Figure 6 shows a typical transmission operating procedure in rule form. Restriction of Powerton unit 5 to less than 800MW is recommended due to real-time outage status information for Line L0302.

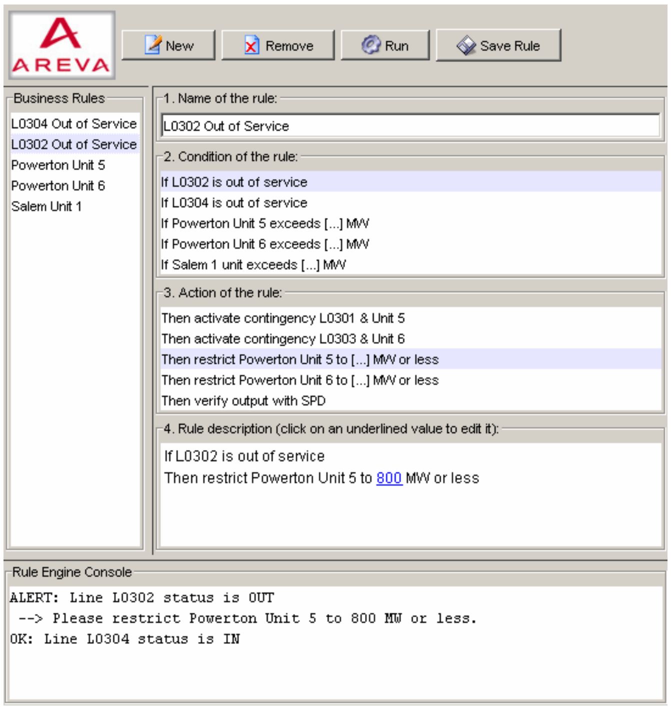


Figure 6. Operator's guide automation

A forward-chaining engine is preferred in this situation since this particular decision support application is mainly data-driven. Real-time data such as system topology and current generations are collected by the RB DSS to derive the recommended actions for system operators.

C. Example 3 – Real-Time Dispatch Advisor

In real-time market, security constrained economic dispatch (SCED) is typically run every five minutes for a few case scenarios of different load forecast conditions. Approved cases will actually be used for dispatch instruction and settlement. Dispatchers have the responsibility to manually approve cases based on their own domain knowledge and experiences. Typically, market operators will observe and compare certain information including zone dispatch rate, system load forecast, deviation of desired dispatch generation from current generation, case execution status, LMP etc. on the main display (Figure 8) for real-time dispatch. Heuristic knowledge and experience of proper relationship among the observed data will dictate if certain solution could be approved. It is envisioned that such domain knowledge and experiences in the form of heuristic rules could be captured in a knowledgebase to ensure operation consistency and avoid human overlook. A backward-chaining engine is preferred in this situation since case approval is a very specific goal.

This knowledgebase could also serve as a resource for training less experienced engineers or market operators in a market/dispatch training simulation environment. It is important to note that the knowledgebase could be fine-tuned by business owners or market operators without involving IT staff for software modification or enhancement. For example, rule-flow shown in Figure 7 could be constructed and modified graphically by end-users without writing any code. This enhances business owners' and market operators' ability to impact application behavior beyond traditional engineering parameter setting.

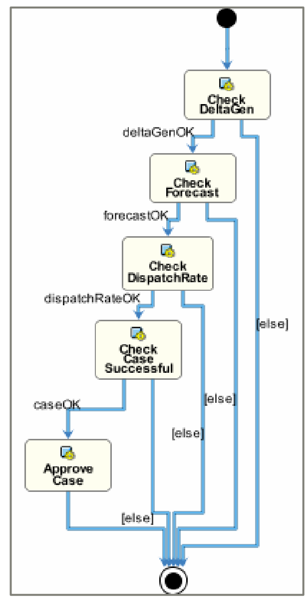


Figure 7. Rule-flow for dispatch case approval

V. Conclusions

This paper presents the challenges of market operations and proposes to adopt rule-based approach to support market operators in making mission-critical decisions. Benefits of using rule-based systems in market operation environment are discussed. Preliminary results illustrate the great potential of applying rule-based technology for decision support in the market operation environment.

VI. Acknowledgment

The views expressed in this paper are solely those of the authors, and do not necessarily represent those of AREVA.

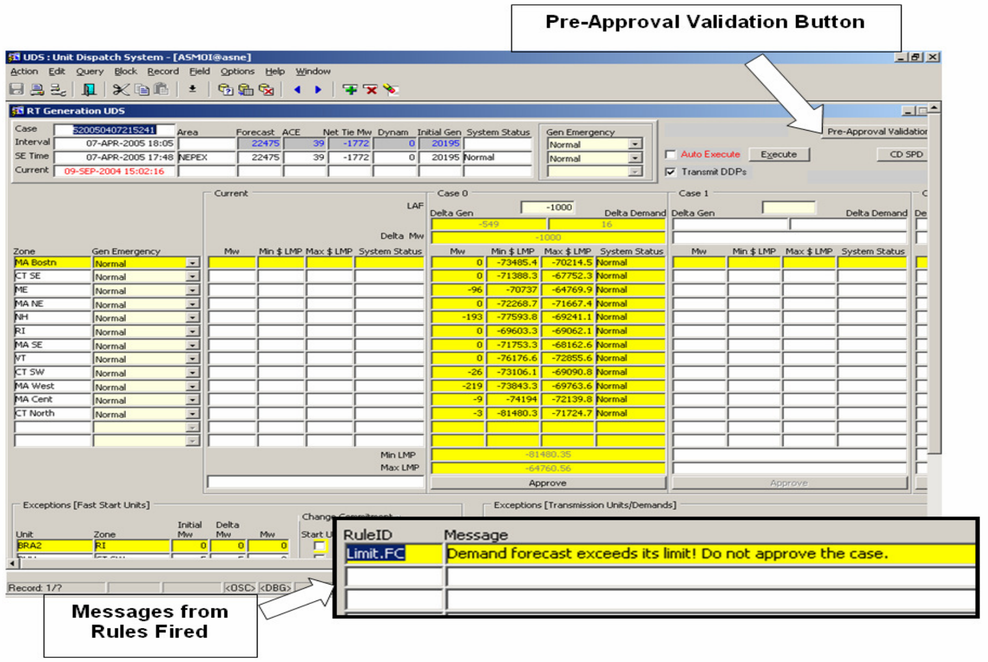


Figure 8. Real-Time Dispatch Main Display

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VIII. Biographies

Kwok W. Cheung (S'87-M'91-SM'98) received his B.S. from National Cheng Kung University, Taiwan, in 1986, his M.S. from University of Texas at Arlington, in 1988, and his Ph.D. from Rensselaer Polytechnic Institute, Troy, NY in 1991, all in Electrical Engineering. He joined AREVA T&D Inc in 1991 and is currently the Manager of the Market Applications team. His interest includes deregulation applications and intelligent systems.

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