Design and Development of an Economic Decision Support Model For Optimal Electrical Power Dispatch

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Abstract—This paper presents a novel architecture of an indigenously developed system in Trinidad and Tobago for Economic Generation and Load Dispatch and its successful implementation. Typical local practices and policy regulations for power industry are discussed along with the power generation and load profiles. The developed system ix-GEMS has different components and several features to assist the control room engineers in economic load dispatch in real-time. Besides real-time operation and control, ix-GEMS also provides training opportunities for load dispatch, based on historical data.

Index Terms—Economic Generation, Economic Load Shedding, Practical Implementation, ix-GEMS, Real Time Operation

I. INTRODUCTION

The problems of economic generation and load dispatch are very well known over the years [4,6,7,8]. At any electrical generation control center there are a large numbers of generators all of which need to be optimally matched to the expected future load requirements of the electricity grid. Optimal dispatch establishes minimum use of non-renewable and increasingly expensive fuel resources. The overall power demand of the network must be met by dispatching to the generators or clustered generation stations or there will have to be load shedding and power outages. Dispatching establishes the load to be delivered by a generator or cluster of generators. The power demand of the small island economies and isolated power networks needs to be forecasted for the medium term as well as for long term planning, since generation infrastructure is a major financial investment [5, 8].

Dispatching the electricity grid load economically across all the generators cannot be done intuitively as the generators have varying individual drooping characteristics and vastly different heat-rate curves. Additionally there are a wide ranging factors such as different makes, different systems and technologies (such as combined cycle generators), power capacities, maintenance states (due to operating conditions and age), generator power up lead times all of which make the economic generation a much more complex problem. Taking into account other real life variables such as generator maintenance schedules and contractual agreements makes the task of dispatching even more overwhelming.

The optimal real time dispatch decision however needs detailed insight into various network operating conditions, time of day, load forecast, demand notices from bulk customers along with powerful complimentary online computational tools and user-friendly intuitive display systems. It is not humanly possible to track these many conditions, requirements and constraints which continuously change in real-time under normal operational conditions. Trinidad and Tobago is a twin-island nation in the Caribbean with a total installed generation capacity of 2,215MW. Traditionally its power sector has been largely managed by the Trinidad and Tobago Electricity Commission (TTEC) and a power generation company “PowerGen”. Effectively to date, there are three Independent Power Producing Companies (IPP)’s. There are also policy making authorities such as the regulatory commissions (RIC) with the Trinidad and Tobago Government being a key stakeholder. The power generation comes from more than 44 generators from 7 geographic areas or stations across the twin island nation. TTEC directly manages some of the generation capacity across the twin island state. PowerGen provides TTEC the ability to work outside some of the business limitations of the power purchase agreements negotiated with the other IPP’s.

For the last century, the economy of Trinidad & Tobago has been driven by the energy oil and gas sector and more recently chemical downstream processing sectors. Over the last two decades, the local economy has been growing consistently in diversified areas such as manufacturing, service, construction and the utilities sectors. The presence of the multinational majors, particularly in the oil & gas sector and their ever expanding state-of-the-art facilities increase the demand for supply of electrical energy especially the Steel smelting plant which induces stochastic loads on the Electricity grid utilizing up to 10% of total electricity generation capacity. There is also an ammonia plant which generates independently but has the potential to impose again another large load on the grid when their internal plants fail.
TTEC can manage the power dispatch across the nation in real time from its central load dispatch center because of Ixanos Technology systems. Traditionally the control operators and engineers rely only their experience using known ‘rules of thumb’ to determine criteria for managing the dispatch of the power to the national grid which is based on the frequency offset from the standard value of 60 Hertz. To address this problem, Ixanos Intelligent Engineering Systems Ltd in collaboration with TTEC and the University of the West Indies has designed and developed a comprehensive solution using state-of-the-art technologies to manage the economic generation and the economic load dispatch problems for the islands of Trinidad and Tobago.

This paper presents the details of these new systems, overall architecture, and the use of technologies such as real-time 3D data visualization systems. This recently developed system includes web-enabled communications and operations, online computation of economic generation with load dispatch solution scenarios in both an offline simulation mode and a real time decision support mode to assist the control center operators and engineers to accomplish optimal economic use of non-renewable fuel resources and post situational analysis.

II. ix-GEMS - OVERALL SYSTEM DESIGN AND ARCHITECTURE

The new system is known as ‘The Generation Economic Management System’ (ix-GEMS) consisting of a Remote data acquisition and Monitoring System (ix-RMS) with a Decision support system for Economic Load Dispatch (ELD) consisting also of a web portal to share information in real time among all the Electricity stakeholders (Providers, The controlling Electricity Commission and the Regulators). The ix-RMS system provides real time access to meter readings at each generator or clustered station. Up to forty different measurements from each meter are transmitted in real time back to a central control room. The overall system design, architecture and various components are shown in figure 1. In depth details of requirements and design are avoided to save the space.

Fig. 1. Overall system architecture and design

The decision support system, the Generator Economic Load Dispatch (ix-GEMS) uses both the historical data as well as the real time data to empower the control engineers toward making the optimal decision. The system provides the expected Load through historical forecasting and utilizes real world variables from IPP’s and their respective PPA’s in the decision support algorithms to aid the engineers in the control room.

The major aim of this successful project is therefore to provide a software platform that captures all relevant data from many sources both engineering and contextual information and also using ix-RMS SCADA to effectively provide intelligent, real time optimal decision support to the control center operators and engineers based on the economics and real world power generation scenarios. Other prominent features and considerations include reducing the stress on the operators in recalling successful remedial measures especially during instantaneous failures to maintain economic generator to load dispatching from their past experiences, or efforts in consulting senior colleagues; to bring down the costs of fossil fuels and thus improve the profit margins of the power company. The system also provides training opportunities by enabling off line analysis using accurate real historical data when the system Simulation Mode is used.

Unlike most of the world, the IPPs in Trinidad and Tobago do not pay for the fuel used to generate electricity. However, they are paid to convert the natural resource fuel through selling the resulting power to TTEC. TTEC is effectively paying IPP’s to convert fuel to electricity with TTEC paying for the fuel itself. The power purchase agreements (PPA) with the IPP’s are contractually predetermined by amount of power to be made available. If TTEC does not use all of the electricity, TTEC still pays for the power made available, reciprocally however if additional power is required above the agreed amount there are penalties to be paid by TTEC. This results in TTEC having a very large incentive to reduce fuel usage and penalties, while the IPP’s have little or no incentive. IPP’s do however have a bonus for meeting certain heat rates requirements. Real world situations compound the system where heavy and stochastic loads are imposed on the grid by industrial consumers. In particular, steel producers in Trinidad and Tobago account for consuming up to 10% of the country’s supply in a relatively stochastically varying pattern.

| TABLE I. TECHNOLOGIES USED IN IX-GEMS |
|------------------------------|----------------------------------|
| ix-GEMS Component | Technologies used in implementation |
| RMS | .NET technologies – C#, VB.NET, ASP.NET |
| ELD | C++, Jscript, HTML, C#, ASP.NET |
| Database | MS SQL Server |

These large consumers may not be able to (or not always cooperative) provide adequate advance warnings to the TTEC control engineers as to when they will place the loads on the national electrical grid. Due to these obvious typical conditions and the inherent nature of island network operations, it is challenging to procure or customize any commercial software to suit the requirements of all stakeholders. The ix-GEMS is designed, developed and implemented by Ixanos, with the active participation of all the
stakeholders. Table 1 show various technologies used in the implementation of ix-GEMS.

III. REMOTE METERING SYSTEM (RMS)

ix-RMS is an important component of ix-GEMS provided by Ixanos that monitors the generation in real-time across the twin island country initially through the polling of individual meters at the generators and lines. This information is provided on a HMI in the TTEC Control Room. The main components of ix-RMS are an IO-Engine, Processing Engine, Historian, Human Machine Interface (HMI) and a data Reporting system. The architecture uses a Publisher-Subscriber model which are both virtual software machines that provide the flexibility for changing the internal system design on the fly to include multiple IO-Engines (which poll the meters) and Processing Engines (which process the received data), with heterogeneous receivers such as the HMI in real-time as well as any other virtual engine such as ix-GEMS. The Economic Dispatch Engine, which will be presented in the following section.

The IO-Engine reads the meters at specified intervals through a variety of protocols of choice including DNP3, MODBUS, and QDIP. The physical connection can be either Serial or Ethernet for DNP3. The wide area communication is done through fiber optics and microwave links from the central control room to the remote meters at each station. These virtual software elements can be re-configured quickly and dynamically for best efficiency, using many IO-Engines, Processing Engines in any configuration necessary. A typical example for real time ix-RMS module is shown in figure 2, which is one of the several screens of our ix-RMS software. It can be seen that for the control room engineer’s the HMI presents the necessary real-time data of choice from all meters to take the appropriate decisions.

One issue found post implementation was that as the number of generators (and meters) increased, sequential polling began to take too long reducing the real-time updates on control room data HMI display. To correct this each meter connection is now polled simultaneously through a multi-threading technique.

Another issue found was that in the case of a major outage, the normal communication systems also fail, while the meters have backup power. To prevent failure of the system to receive data and to maintain visibility in the control room, a backup 3G Mobile network communications system can be used since the phone network is more robust having its own backup battery systems. The IO-Engine will then still be able to publish the meter data points to the ix-RMS meter subscribers. This provides visibility of the generation plants during recovery. The IO-Engine also simultaneously forwards all the data points it has received to a historical database through a message queue for archiving without disrupting the IO-Engines real time processing.

The system also provides the engineers with trending, which is shown in figure 3. This means, using ix-GEMS engineers will be able to restore the system smoothly from major outages, coupled with communication issues. From this it can be seen the flexibility and reliability design features of the ix-GEMS. The simulation mode of the ix-GEMS can also provide the Engineers with a post situation black out analysis tool for the entire electrical network.

Finally the HMI is what the control room operators and engineers use to see real-time data and trending. What is displayed on the HMI is user configurable, including where and how it is displayed, for example charts and flat graphical displays. Any tag from the Processing Engine can be displayed and the HMI will automatically subscribe to the necessary Processing Engines to get the requested data. The HMI provides multiple panels on which the user’s desired controls can be added. Workspaces are collections of Panels and can be used for different classes on users who will need to see different information from the meters.
IV. ECONOMIC LOAD DISPATCH SYSTEM (ELD)

The Economic Load Dispatch (ELD) engine primarily provides unassisted automatic dispatch per generator or per station, but the user can also choose to see the recommended unit dispatches for human action. The ELD engine uses real-time information from the ix-RMS system to compute the best load dispatch possible using two well-known algorithms (Lagrange Multipliers and Incremental method) and displays this information on the 3D interactive graphical user interface (GUI) in the Control Room. Figure 4 shows loads on different, user (by the operator) selected stations/generators. It can be seen that even previous and present loads are presented to the decision algorithm and then the dispatch is re-run iteratively until all constraints can be met.

The incremental method uses the derivative of the heat rate formula to determine where it would be most economical (cheapest) to pick up or drop the next increment of power providing an optimal return on investment (ROI).

Fig. 4. Stations Past Load and Forecast Trend

This process is repeated until the entire power demand is met. The Lagrange method uses Lagrange Multipliers to find the minimum cost to provide the total power demand. To ensure constraints are not violated, whether machine characteristics or artificial user or contextual, different types of constraints are imposed, the necessary restrictions are applied to the decision algorithm and then the dispatch is re-run iteratively until all constraints can be met.

Fig. 5. Holistic 3D Display with Embedded Dispatch Forecast and Trend Charts

DisDispatches are triggered when the system frequency goes out of a set threshold (driven by the changes in total load), thus requiring addition or dropping of generation capacity to correct the frequency to the set point of 60Hz.

The dispatch can provide a pure engineering dispatch or be configured to consider the real life and artificial constraints, such as those in the Power Purchase Agreement (PPA), current system issues, for example, a transmission line to a station may fail and so reduce the power that can be provided by that station to the grid, among other user constraints such as a generator may be go down for maintenance.

The Lagrange method will quickly inform how best to dispatch all the operating generators at any instant, whereas the incremental method will inform where best to pick up or drop off the next increment of power and thus is better for an already running non-optimum system. Over time with enough oscillations of power demand the incremental method will eventually reach the Lagrange optimization of power distribution.

After a dispatch has been generated restrictions are logically applied; first the generator characteristics (max/min power) then user input restrictions such as Generator, Station, and the PPA restrictions. If any restriction fails to be met, appropriate limitations will be applied and the dispatch will be re-run. The classical Lagrange method and incremental methods [9] are used in this work and details are out lined for the sake of completeness.

A. Lagrange Method

\[ \lambda = \frac{P_D - \sum_{i=1}^{NG} b_i}{\sum_{i=1}^{NG} \frac{1}{Z_{Ni}}} \]

Power \( P_i \) for the \( i^{th} \) generator:

\[ P_i = \lambda - b_i \]

Where, \( P_D \) = Power Demand; \( NG \) = Number of generators; \( P_i \) = Dispatch for \( i^{th} \) generator; \( a, b \) and \( c \) = Heat rate coefficients.

Constraints are then tested, that is, power min and max for the generator, if violated, e.g. too low, setting that generator to its minimum power, subtract that power for the power demand, then re-dispatch the load to the remaining generators. The generator with the highest over-power is restrained first, and the Lagrange repeated until there are no more over-powered generators, then this is repeated for under-powered generators (largest underpowered first).

B. Incremental Method

For the incremental method, the following formula is used:

\[ dC_i = (2aP_i + b) \, dP_i \]

Where, \( dC_i \) = incremental cost increase of generator \( i \) as a result of incremental power increase \( dP_i \).
This will be tested on all running generators, and the machine with the smallest $dC_i$ (on increasing power, largest for decreasing power) selected unless this would cause constraint violation, then the method repeated until then necessary power demand is met.

C. Restrictions Framework

Once a dispatch has been found that meets the generator characteristics, this dispatch must also be tested against the user input restrictions. This is achieved by iterating through each restriction and testing if the restriction is met, if it hasn’t, appropriate limits are placed on the system before attempting a re-dispatch.

Currently the following restrictions are supported:
1. Generator max/min (this is a further restriction over the generator characteristic)
2. Station max/min
3. PPA max/min – To be implemented

V. REAL TIME ECONOMIC LOAD DISPATCH

Training for the operators and engineers is very essential on a continuous basis. Further, it is important that real world and specific operating conditions related to the very network are presented to the operators and engineers, that they are expected to handle on a daily basis [6, 7]. The real-time load dispatch is designed in such a way that operators can use a live mode for real-world network operations and decision support as well as in a simulation mode for training purposes and post incident analysis. The Live dispatch is achieved through integration to the RMS System via two methods;
1. Directly from the ix-RMS Subscriber as in the Real time Mode
2. Database Historical polling as in the Simulation Mode

A. Live Dispatch

First the GEMS module will pull generator and configuration information from the database and try to subscribe to the RMS Processing Engine to get updates and system changes. Where a timeout has expired since the last publish from the Processing Engine, GEMS will fall back to poll the database for the needed information. Once an update is received (whether through publish or a database read) the system frequency is checked to see if it is within tolerance or unchanged since last dispatch, if not a dispatch is attempted. The power demand is calculated by using the given frequency multiplier against the difference in frequency from ideal (for example, 5MW per 0.1Hz). The calculated dispatch is saved back to the database where the frontend retrieves and presents it for user action and/or acknowledgement after which it is made visible by the secure Web portal to the respective generation provider, IPP or station.

B. Simulation Dispatch purposes

Apart from Real-time operation, a simulator mode is provided for offline analysis. In this mode a time period and the stations can be specified as well as respective constraints added to produce a simulation of a best case dispatch over the time period. The simulation can be used to compare scenarios (with different constraints) and algorithms. This modeling will allow investigation into how changes in PPA variables and other real life variables will affect the power generation system and economics.

VI. 3-D VISUALIZATIONS

A “gaming” user interactive approach is used to create an intuitive 3D active display. This assists and encourages the Control Operators and Engineers in their decisions and investigations. The user interface must both be easy to use and intuitively provide the necessary information and views. Gentle Data cleansing and smoothing is first done on the data to provide a more useful visual display using techniques such as moving averages. Parallel processing using NVIDIA graphical cards to perform the data processing is being tested for faster simulation and also visual modeling. The 3D display developed provides the details of the power provided by each station historically, over the last few hours as well as a forecast of expected power for the next few hours.

The 3D display and embedded trend charts allow users to interactively isolate a station on the display for further analysis. This isolation can be done through the control menu provided or by keyboard and mouse shortcuts.

![Fig. 6. 3D ix-GEMS HMI: Reporting and Forecasting the Trend](image)

A particular data point and value on the 3D chart can also be seen by clicking on the display screen. The rows in the display can be rotated, or the entire chart rotated 360 degrees to view from any angle also there is a zoom in and out feature to accommodate any desired level of detail in the view.

Each IPP station is provided with a login to a secure web portal that details the power being provided by them and includes planned expectations, changes in dispatch for the respective IPP as directed by the TTEC control room over the next few hours taking into account for any lead time necessary for the changes. The IPPs’ are also provided with a similar 3D Display and Trend chart as in the diagram below with similar features but they will only have visibility of their own generators and/or lines. TTEC issues its current dispatches to the stations through this web portal both removing the need to radio or call as well as providing an definite audit trail.
VII. CONCLUSION

A successful implementation experience of an economic decision support system for optimal power dispatch using the state-of-the-art technologies is presented. Overall system architecture and its components have been discussed. Using this system, control engineers will be able to take effective decisions due to the fact that the ix-GEMS analyzes both real-time and historical data, computes necessary parameters. Then dispatch decisions are presented along with the supporting information in 3-D. ix-GEMS is an example of a successful case of developing the necessary technical solutions indigenously within the Caribbean.

REFERENCES