HYBRID TECHNIQUE LOAD FORECAST AND ESTIMATION FOR UPSTREAM OIL & GAS INDUSTRY

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Abstract - Investment in the infrastructure of the power generation is one of the key portions of Oil & gas production projects. This infrastructure shall cover all power demand of production facilities as sales agreement and long-term field development plan. The load forecast and estimation shall be developed at the early phase to identify the power demand which significantly impacts project CAPEX.

As the normal practice, the total load demand is calculated based on equipment rating. This works well for midstream and downstream. However, this method might not result as well as others for upstream due to uncertainty from process variation and production profile.

The "Hybrid Technique" was thus implemented in two (2) Oil fields in 2014 and 2017 which results in $30 million saving and six (6) months early production gain.

This paper is to describe the new methodology to estimate better load forecast by using precess operation data into account. This method has been proved with good results in those two projects.

Index Terms — Hybrid technique, Load forecast, Load estimation.

I. INTRODUCTION

At the early stage of the oil and gas upstream project, it is necessary to estimate the power consumption correctly to ensure that the operation can operate smoothly without a power shortage, resulting in a financial return as planned. However, the power consumption can change over time due to the change in production volume and requirement over the production asset lifetime. The new load forecast will be used to determine the change in infrastructure development.

The accuracy of the load forecast is key to determine the CAPEX of the project. The over-estimation will result in oversized electrical infrastructure. On the other hand, the under-estimation might lead to production deferment, additional investment costs for infrastructure upgrade and expansion.

This issue occurred at Thailand's Oil field in 2013. This Oil field comprises one (1) Central Production Facility station, four (4) Local dehydration stations, and more than 300 operating wells. In order to achieve the company production target, this field was planned to increase crude oil production by increasing the number of artificial lift equipment (i.e. beam pump, progressive cavity pump or PCP and electrical submersible pump or ESP) and unlocking all de-bottlenecking points in the production facility. This new equipment required a large electrical power supply at various well site locations; hence, several electrical projects were thus initiated e.g. power generation system upgrade, 22 kV transmission network system extension, and new additional electrical distribution system.

At the early stage, the electrical load forecast was developed as per the field development plan and normal engineering practice. The result showed that electrical load would rapidly grow and reach 34.91 MW by 2021 which is greater than the in-plant power generation capacity by 11.21 MW. Therefore, additional power generation is needed.

The feasibility study of this 11.21MW additional power was conducted for finding the most economical solution. This study showed that 'co-generation between electricity and steam' is the best option for both technical and economic viewpoints. The estimated investment is about $30 million.

During 2012-2013, before the financial investment decision of the new power plant, the argument on the precision of the electrical load forecast (version 2013) was raised within the engineering team because from the calculation, the estimated load was about 27 MW but the actual load was only 12-14 MW. Therefore, the revisit on load forecast calculation was deeply investigated.

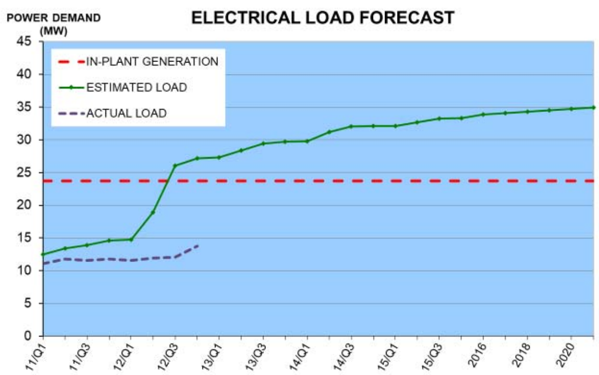

Fig. 1 The existing electrical load forecast

II. GENERAL ENGINEERING PRACTICE OF LOAD CALCULATION (NORMAL METHOD)

The general engineering practice of load calculation (normal method) has been widely used to calculate total load demand in all industrial plants. One of the best references is "Handbook of Electrical Engineering: For Practitioners in the Oil, Gas and Petrochemical Industry" by Alan L. Sheldrake [2]. Prior to calculating total load demand, each load (vital, essential, and non-essential loads) shall be reviewed and divided into typically three duty categories:

- Continuous duty;
- Intermittent duty;
- Standby duty (those that are not out of service).

Hence the total load consumption of each switchboard will usually be determined from an amount of these three categories. Call "*C*" for continuous duty, "*I*" for intermittent duty, and "*S*" for the standby duty. Let the total amount of each at a particular switchboard *j* be C_{jsum}, I_{jsum}, and S_{jsum}. Each of these totals will consist of the active power and the corresponding reactive power.

In order to estimate the total consumption for the particular switchboard, it is necessary to assign a diversity factor (*D*) to each total amount as per their operating nature. Let these factors be D_{cj} for C_{sumj}, D_{ij} for I_{sumj} and D_{sj} for S_{sumj}. Different types of plants may apply different diversity factors.

Table I shows the range of suitable diversity factors. The factors should be chosen in such a manner that the selection of main generators, transformers and main feeders are not excessively rated, thereby leading to a poor choice of equipment in terms of economy and operating efficiency.

TABLE I
DIVERSITY FACTORS FOR LOAD ESTIMATION

Type of project	D_c for C_{sum}	D_i for I_{sum}	D_s for S_{sum}
Conceptual design of a new plant	1.0 to 1.1	0.5 to 0.6	0.0 to 0.1
Front-end design of a new plant (FEED)	1.0 to 1.1	0.5 to 0.6	0.0 to 0.1
Detail design in the first half of the design period	1.0 to 1.1	0.5 to 0.6	0.0 to 0.1
Detail design in the second half of the design period	0.9 to 1.0	0.3 to 0.5	0.0 to 0.2
Extensions to existing plants	0.9 to 1.0	0.3 to 0.5	0.0 to 0.2

The total load can be considered in two forms as follow:

$$TPRL = \sum(D_c C_{sumj} + D_i I_{sumj}) \quad (1)$$

$$TPPL = \sum(D_c C_{sumj} + D_i I_{sumj} + D_s S_{sumj}) \quad (2)$$

Where

TPRL	Total plant running load (kW)
TPPL	Total plant peak load (kW)
D_c	Diversity factor for continuous load
C_{sumj}	Total continuous load for switchboard *j*
D_i	Diversity factor for intermittent load
I_{sumj}	Total intermittent load for switchboard *j*
D_s	Diversity factor for standby load
S_{sumj}	Total standby load for switchboard *j*

The above method can be used very effectively for estimating power requirements at the beginning of a new project, when the details of equipment are not known until manufacturers provide adequate information i.e. installed rating, load factor, efficiency and power factor; hence a more accurate version of load schedule can then be rectified.

Total plant running load (TPRL) is normally taken into account to select power sources e.g. gas turbine, diesel engine, gas engine, solar PV, wind turbine, receiving power from grid, etc. In parallel, the total plant peak load (TPPL) will be brought to the selection of power source and distribution equipment rating e.g. generator, transformer, and feeders.

Oil companies are used to apply this approach with different diversity factors based upon experience gained over many years of plant design and their operating paradigm.

Nevertheless, this practice still has some flaws which led to inaccurate plant load estimation. Therefore, further investigation on the practice was conducted and discussed in other relevant sections in this paper.

III. INVESTIGATION OF THE EXISTING LOAD FORECAST

A. Data gathering

It is necessary to gather data that directly and indirectly relates to load forecast preparation in order to identify the gap between the existing load forecast study and actual plant operating conditions. The gathered information is as below:

1) The existing load forecast study and calculation: to understand the calculation method and assumption;

2) Equipment manufacturing data i.e. pump performance curve, pump data sheet, etc.: to understand equipment behavior that impacts power consumption;

3) Field development plan: the production profile, water injection profile, and future development projects, artificial lift plan, etc.

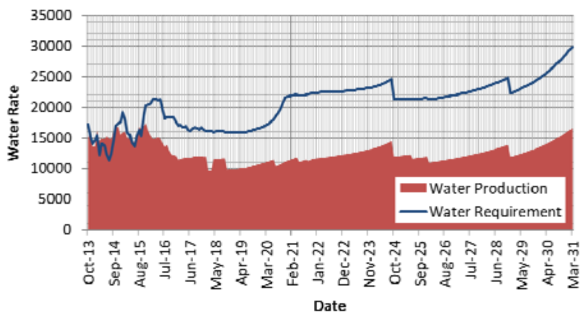

Fig. 2 Example of local dehydration water profile

TABLE II
ARTIFICIAL LIFT PLAN (ACCUMULATED UNIT)

Description	2013	2014	2015	2016	2017	2018
Beam Pump (BP)	171	210	250	271	307	336
Electric Submersible Pump (ESP)	37	57	59	61	62	63
Progressing Cavity Pump (PCP)	7	7	7	7	7	7

4) PI ProcessBook data (real-time process data system): all available online digital data from the PI system were extracted to study actual equipment operating conditions e.g. pump status (start/stop), pump flowrate, etc.

5) Field daily report: production rate (crude and water) and plant power consumption.

6) Additional field data e.g. actual load power usage and actual load operating time were recorded.

B. Finding

1) Error from Typical load factor

In order to avoid delay of long lead electrical equipment (generator, transformer, etc.), the equipment sizing, and equipment selection shall be completed at the early stage of the project. Normally, the actual load factor is not available at this period, therefore, the typical load factor from API 610 [1], Table III, is adopted in the total load consumption calculation. However, after the project is completed, each load factor was never been updated to the final document. To eliminate the error, the actual load factor as gathered from the manufacturing document was updated in the new calculation.

TABLE III
LOAD FACTOR OF MOTOR DRIVEN PUMP

Motor Nameplate Rating		Percentage of Rated Pump Power	Load Factor
kW	HP		
<22	<30	125	0.80
22-55	30-75	115	0.87
>55	>75	110	0.91

2) Incorrect diversity factor

The diversity factor of the beam pump was found that it was incorrect. Beam pumps are the biggest load at well sites (more than 300 units were planned to be installed within 2017, with 45kW each), thus, the incorrect diversity factor significantly affected calculation accuracy. According to the existing load forecast calculation, the diversity factor of 1.0 was used but in fact, the diversity factor of the beam pumps is difficult to specify due to their unpredictable character subject to well's conditions. From observation, some units operated all the time while some operated only 10% or less, depending on their subsurface conditions and operation adjustment. Thus, the status of beam pumps (on/off), was extracted from the PI system and used in the calculation. As a result, the average diversity factor (percentage of operating time) of the beam pumps is only 0.49, 51% saver compared to the original design figure, and was updated in load forecast calculation.

3) Uncertainty of sub-surface characteristics

Uncertainty is the nature of the upstream business. It is hard to determine subsurface formation and behavior; therefore, during the early development phase, all possible scenarios are considered for the equipment selection. Most of the equipment ratings are selected to serve a wide operating range and flexible for various scenarios. The actual operating point is changed as per the dynamic of subsurface information and profile.

However, the load forecast study was calculated using the aforesaid equipment's design rating with a typical load duty factor. Therefore, the outcome of the study did not correlate with the actual operating conditions (flow rate, pressure, etc.). This is found as the key root cause for the discrepancy between the load forecast and the actual power usage.

According to this finding, it can be concluded that the normal engineering practice, which commonly uses in the oil and gas industry. may not fit for all cases especially in the oil field which has sub-surface uncertainty. To optimize the design and selection, a new specific methodology was developed in 2014.

IV. HYBRID TECHNIQUE METHOD

A. Model

The new methodology is initiated so called "Hybrid technique load forecast and calculation". The approach needed a tight collaboration between the electrical engineer, process engineers, operation team, and asset planning team in order to understand actual plant facility behavior. All field data e.g. actual load power usage and actual load operating time was used and analyzed in a multi-view of operating paradigm. It was found that load calculation should not base on only electrical and mechanical design parameters but also hidden parameters that impact the plant demand significantly i.e. equipment behavior and availability.

With the electrical load forecast including operational data analysis, the "Hybrid technique load forecast" was successfully developed. This method had never been applied to any oil and gas industries. The key concept of the idea is to establish and implement several calculation models to include operational behavior parameters as shown below:

The normal load forecast method:

$$\text{Total loads} = \sum L_i \times D_i \qquad (3)$$

Where

L_i Equipment design's load
D_i Equipment diversity factor

The hybrid technique load forecast method:

$$\text{Total loads} = \sum L_i \times D_i \times B_i \qquad (4)$$

Where

L_i Equipment design's load
D_i Equipment diversity factor
B_i Equipment behavior factor

The equipment behavior factor is the correlation factor between power consumption at the operating conditions and design conditions. Each equipment category (pump, compressor, etc.) will have its characteristic between power consumption and operating conditions (flow rate, pressure, etc.). Moreover, the investigation also shows that most of the equipment with dynamic operating conditions is the pump. Therefore, the motor-driven pump's behavior factor was focused on in this study.

Behavior factor for pump

The relation between power consumption and operating conditions are as follow:

$$L \ \alpha \ F \times \Delta P \qquad (5)$$

Where

L Pump load or output power
F Pump flow rate
ΔP Pump difference pressure between suction and discharge

Since the difference pressure of the pump is quite stable, the relation between power consumption and operating conditions can be simplified as follow:

$$L \propto F \quad (6)$$

Thus, the pump's behavior factor can be calculated as below:

$$B_i = F_{io} / F_{id} \quad (7)$$

Where

B_i	Pump behavior factor
F_{io}	Pump operating flow rate
F_{id}	Pump designed flow rate

In addition, from historical data analysis, it was found the special operating condition of the artificial lift pump is pump availability. Since several artificial lift pumps have been installed without ramping up the maintenance team, resulting in less than 100% availability. This analysis also helps the maintenance team to identify their lack of manpower and a new target to improve the availability of artificial lift equipment.

TABLE IV
ARTIFICIAL LIFT EQUIPMENT AVAILABILITY

Description	**2014**	**2015**	**2016**	**2017**
Beam Pump (BP)	70%	71-82%	83-90%	90%
Electric Submersible Pump (ESP)	70%	71-82%	83-90%	90%
Progressing Cavity Pump (PCP)	100%	100%	100%	100%

Therefore, the artificial lift pump's behavior factor can be modified as below:

$$B_i = (F_{io} / F_{id}) \times A_i \quad (8)$$

Where

B_i	Pump behavior factor
F_{io}	Pump operating flow rate
F_{id}	Pump designed flow rate
A_i	Pump availability factor

After the estimation of the new load consumption method was completed, the total running and peak loads from such kind of load categories (continuous, intermittent, and standby) were achieved. Finally, the hybrid model verification was performed to fine tune the parameters of each load type against the actual load at operating conditions.

B. Model validation

For proof of the concept of using a new model methodology, the validation process had been examined with the historical actual three years plant load as per Table V.

TABLE V
Model Validation assessment result

Date	Actual Peak load (MW)	Model Peak Output (MW)	Difference (MW)
20-Jan-11	14.27	14.91	0.64
19-Mar-11	12.06	11.55	-0.51
19-Apr-11	13.47	12.73	-0.74
19-Jun-11	12.64	12.70	0.06
19-Jul-11	13.18	12.58	-0.60
18-Oct-11	10.20	11.83	1.63
19-Jan-12	13.07	13.53	0.46
19-Mar-12	12.50	12.25	-0.25
18-Apr-12	12.00	11.91	-0.09
19-Jun-12	13.01	11.91	-1.10
19-Jul-12	12.54	12.32	-0.22
19-Oct-12	14.47	13.57	-0.90
18-Jan-13	15.25	14.66	-0.59
20-Mar-13	15.93	14.74	-1.19
18-Apr-13	16.83	16.89	0.06
19-Jun-13	16.89	15.57	-1.32
18-Jul-13	17.00	15.53	-1.47
18-Oct-13	14.31	15.53	1.22
18-Jan-14	15.70	15.85	0.15
19-Feb-14	15.11	15.83	0.72
20-Mar-14	13.99	15.29	1.30
17-Apr-14	14.17	15.20	1.03
Average of difference (MW)			-0.08

The results of the sampling show that the output from the model is close to the actual load. The average difference between model output load and actual load is about -0.08 MW which is technically acceptable.

V. RESULTS

Load forecast is plotted and shown as below:

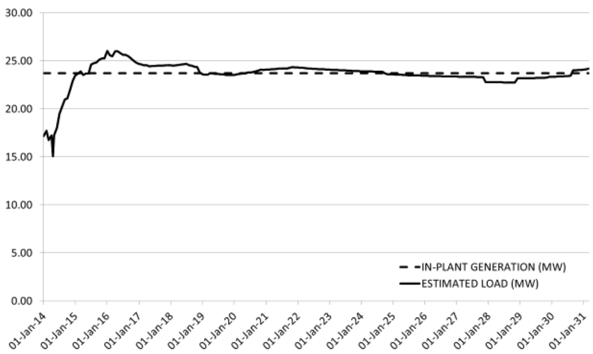

Fig. 3 New load forecast with Hybrid technique

The result from the new load forecast is summarized as below:

- In-plant generation remained at 23.7MW;
- The estimated load forecast would reach the highest demand of 26.05MW in January 2016 and decline down to 22.76 - 24.30MW as per Fig.3 between 2017 and 2031 before landed at 24.19 MW in the year 2031;
- During 2014, the estimated load forecast rapidly increased from 17.14MW to 22.92MW (5.78 MW) from the following activities:
    - o Water profiles are rapidly increased from 29,347 Barrel Per Day (BPD) in January 2014 to 80,155 BPD in December 2014;

- 59 units of artificial lift (39 beam pump units and 20 oil ESP units) will be installed in the year 2014.

From the validation, no significant difference between the hybrid load forecast and the actual plant load is found; therefore, it is proved that the new hybrid technique load forecast model is more accurate and can be used for future estimation.

VI. ANOTHER USED CASE IN ONE OF THE OIL FIELDS

One of the oil fields planned to increase its production from 20,000 BPD to 40,000 BPD by plant expansion project. The project comprises production facility upgrades and a new facility to enhance oil production. The electrical power consumption was expected to increase from 15.13 MW to 30.48 MW while in-plant power generation was only 18 MW. Thus, electrical facilities in several areas need to be upgraded i.e. new gas turbine generator (GTG) and switchgear extension. Refer to the electrical load schedule calculation, the total load during the first oil milestone is 27.58 MW which requires the new GTG. Since GTG has a long lead time from ordering to delivery and becomes the longest bottleneck in the process, the project schedule of additional oil production was originally set according to this delivery time.

During tendering preparation, there was an issue raised on the precision of electrical load calculation because the actual load was only 10 – 12 MW compared to the calculation of 15.15MW. The re-visit of load calculation is initiated.

The same root cause is found in this field. Thus, the “Hybrid Technique” was used to improve the electrical load calculation. The investigation also shows that most of the equipment which operate with the dynamic operating conditions are pump and compressor. Therefore, the study is focused on the behaviors of pumps and compressors in field operation. The pump’s behavior factor is shown in section IV “Hybrid Technique Method” while the compressor’s behavior factor is as below

<u>Behavior factor for compressor</u>

Per the thermodynamic calculations of the polytropic process, the relation between power consumption and operating conditions are as follow:

$$L \propto F \times [(P_2/P_1)^{\{(K-1)/(K \times E_p)\}} - 1] \quad (9)$$

Where

L	Compressor load or output power
F	Compressor flow rate
P_1	Compressor suction pressure
P_2	Compressor discharge pressure
K	Adiabatic exponent (constant parameter)
E_p	Polytropic efficiency (constant parameter)

Since the suction and discharge pressures of the compressor are quite stable, the relationship between power consumption and operating condition can be simplified as follow:

$$L \propto F \quad (10)$$

Thus, the compressor’s behavior factor can be calculated as below:

$$B_i = F_{io} / F_{id} \quad (11)$$

Where

B_i	Compressor behavior factor
F_{io}	Compressor operating flow rate
F_{id}	Compressor designed flow rate

After the above information is considered to the new model, the validation process was carried out by comparing the model outcome with the historical data. The hybrid method was proven for its accuracy.

The estimation result with “Hybrid Technique” is as shown in the figure below:

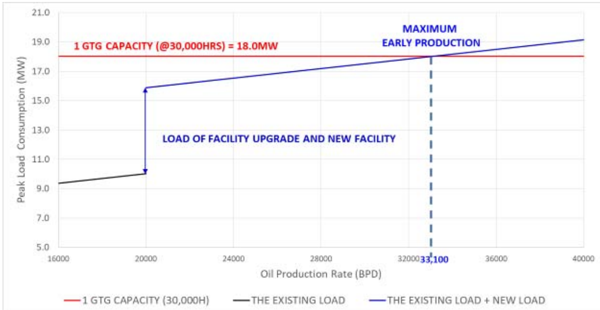

Fig. 4 Electrical load estimation vs asset production

By study results from the hybrid calculation model, the existing in-plant power generation can support production up to around 33,100 BPD. Therefore, the plant can start to gain more production from 20,000 to 33,100 BPD immediately after the installation of other facilities without the new GTG installation, resulting in 6-month of early production gain

VII. RECOMMENDATION

Although the model for the operating field was already developed based on actual operating conditions as mentioned in the hybrid technique, there are uncertainty factors from major activities and changes of the production development plan. If these factors deviate from the original assumption, the accuracy of the load forecast will drop dramatically and lead to a wrong financial decision. It is recommended to regularly review and keep updating load forecast and estimation to ensure the high accuracy of the calculation.

Moreover, it is to be noted that there are many assumptions in the calculation. In case high accuracy is required, the individual pump characteristic shall be determined in the model one by one. Operating data of the major equipment should be recorded for deep analysis. By this technique, load behavior and availability shall be precisely specified for high quality modeling development.

VIII. CONCLUSIONS

From the result of the “Hybrid Technique” method, it is proven that this new method is suitable for the upstream oil and gas business which has an uncertainty from process variation and production profile. This technique requires both normal engineering practice, multi-discipline knowledge, and historical operating data to support the modeling.

The “Hybrid Technique” was successfully implemented in two (2) Oil fields in the year 2014 and 2017, saving $30 million in CAPEX and an early production gain of six (6) months.

The innovation of the “Hybrid Technique” load forecast methodology becomes one of the key decision tools for future investment and development of power generation for the upstream.

IX. ACKNOWLEDGEMENTS

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X. REFERENCES

[1] API STD 610 Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries

[2] Alan L. Sheldrake, *Handbook of Electrical Engineering: For Practitioners in the Oil, Gas and Petrochemical Industry*.

XI. NOMENCLATURE

TPRL	Total plant running load (kW)
TPPL	Total plant peak load (kW)
BP	Beam pump
ESP	Electrical submersible pump
PCP	Progressing cavity pump
BPD	Barrel Per Day
GTG	Gas Turbine Generator
D_c	Diversity factor for continuous load
C_{sumj}	Total continuous load for switchboard *j*
D_i	Diversity factor for intermittent load
I_{sumj}	Total intermittent load for switchboard *j*
D_s	Diversity factor for standby load
S_{sumj}	Total standby load for switchboard *j*
L_i	Equipment design’s load
D_i	Equipment diversity factor
L	Equipment load/output power
F	Equipment flow rate
ΔP	Pump difference Pressure between suction and discharge
B_i	Equipment behavior factor
F_{io}	Equipment operating flow rate
F_{id}	Equipment designed flow rate
A_i	Equipment availability factor
L	Equipment load/output power
P_1	Compressor suction pressure
P_2	Compressor discharge pressure
K	Adiabatic exponent (constant parameter)
E_p	Polytropic efficiency (constant parameter)

XII. VITA

Boonyalit Tangjitkongpittaya graduated from Chulalongkorn University in Thailand in 2004 with an honors degree in electrical engineering. He has 17 years of experience in power system studies & calculations, conceptual and detailed engineering, relay coordination study, equipment specification, project management, construction supervision, and commissioning. He is currently an electrical maintenance engineer with PTT Exploration and Production Public Company Limited.
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