Energy Cost Aware Batch Job Scheduling Policy with Consideration of Time of Use Energy Pricing Model

New Mexico

Supercomputing Challenge

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1 EXECUTIVE SUMMARY

In this computer science project, I use NetLogo agent based simulation program to model the energy cost of batch job scheduling and processing in data centers and high performance computing facilities. Inspired by soaring energy cost problems in today's data centers and high performance computing facilities, I explore energy cost reduction approaches on batch job scheduling policies which work best to handle the batching job requests [6]. Batch applications are commonly seen in most organizations in large part because many common business processes are amenable to batch processing. Normally latency is a key concern for job scheduling and processing. In batch job processing latency is less critical compared to resource allocation fairness. Also the energy bill is a hidden factor in overall operation cost. I concentrate on studying batch job processing solutions in order to reduce energy cost.

I have implemented two batch job scheduling policies. The first one is based on the First-Come-First-Served (FCFS) job scheduling policy. FCFS is a service policy where the processing requests of customers or clients are dispatched to computing facilities in the order that they arrived, without other biases or preferences. The second proposed scheduling policy is based on the Energy Cost Aware Job Placement (ECAP) job scheduling policy. In the ECAP scheduling policy, estimated energy cost of a job and current available ”Time-of-Use” time sector are considered on job placement decision making. The NetLogo, An agent based simulation software, was used to develop two batch job scheduling policies. I used random number functions to generate various batch job workloads and applied them on those two scheduling policies. I have conducted lengthy and intensive simulation tests on proposed scheduling methods. I collected statistic data and performance data in terms of job energy spending cost and system utilization. Finally I used the results of performance testing to judge the qualities of each scheduling policy.

2 STATEMENT OF THE PROBLEM

2.1 Introduction

In the past 10 years, electricity used by the global digital ECO computing system is increasing dramatically. To process very large data sets and challenging scientific applications energy cost is a significant portion of a overall operation cost of modern data centers and HPC computing centers. It was reported in Amazon that the cost of a hosting data center with 15 megawatt (MW) power facility is high as $5.6 M per month[10]. I used the term "High Performance data processing center (HPDC)" to represent data centers and HPC computing centers.

HPDC mostly process two types of jobs: batch jobs and service jobs [10]. In general a service job is an interactive computer service. An interactive computer service is any information service, system, or access software provider that provides or enables computer access by multiple users to a computer server, including specifically a service or system that provides access to the Internet and such systems operated or services offered by libraries or educational institutions [8]. Batch jobs are processed in the data centers without user interaction [1][2]. A batch job is submitted on the computer; the job reads and processes data in bulk— perhaps terabytes of data— and produces output, such as customer billing statements, accounting data processing, big data analytics (meteorology, complex physics simulations, and biological and environmental research). Volumes of batch job processing dominate most of the processing time and system resources. Processing batch job is also the major operation income source of HPDC centers.

It is a new challenging task to cost-effectively operate a HPDC facility and meet the business demands of a more competitive marketplace with budget limitations imposed by today's soft economy [12]. People are seeking various solutions to reduce operating expenses. Energy cost is the most invisible operation expenses consumed largely by servers and coolers.

"Time-of-Use" is a energy pricing strategy used by many energy suppliers and energy distributers. Energy providers or energy suppliers can vary the energy price depending on the time-of-day when the energy is provided or delivered. The principle of using time-of-use pricing is used to meet the balance of supply and demand during time. "Time-of-use" energy pricing includes (1) fixed "Time-of-Use" rates for electricity and public transport and (2) dynamic pricing reflecting current supply-demand situation. "Time-of-Use" energy pricing refers to a specific practice of a supplier. "Time-of-Use" energy pricing is also varied from location to location and season-to-season.

A scheduled batch process consists of the execution of hundreds or thousands of jobs in a pre-established sequence. It can shift the time of job processing to when the computing resources are less busy. It avoids idling computing resources with minute-by-minute manual intervention and supervision [5][6][7][11].

2.2 Research idea

Without real-time consideration and constrain, it is feasible and acceptable to arrange job execution order based on job's power consumption and time-of-use energy pricing model. In this project, I concentrated on batch job scheduling and studied the benefit of applying "Time-of-Use" energy pricing model in batch job schedule. The purpose of this research was to investigate cost-effective batch job scheduling policies when "Time-of-Use" energy pricing is considered and to study how operational cost of computing servers is reduced because of "Time-of-Use" consideration. There are major targets in this research: reducing energy costs, affecting system utilization only minimally, and preserving fairness.

3 DESCRIPTION OF THE METHOD

3.1 Simulation software design

Definition of agents

- Workload generator agent: Use NetLogo's random number functions, such as random(), random-normal(), and random-Poisson()[13]. Random number functions are used to generate number of jobs, job arriving time, and job-estimated energy cost.

- Scheduling agents:
    - ❖ First-Come-First-Served (FCFS) batch scheduling agent: Arrange job dispatching order based on job's arriving time only.
    - ❖ Energy Cost Aware Job Placement (ECAP) scheduling agent : Arrange job dispatching order based a job's estimated energy cost and Time-of-Use energy pricing information.
- Execution Emulator agent: Monitors a dispatched job and countdowns job-finished time and call data collection agent to summarize a job's statistic and performance data when a job is finished its execution.
- Statistic and performance data collection agent

Figure-1 illustrates the relation between agents.

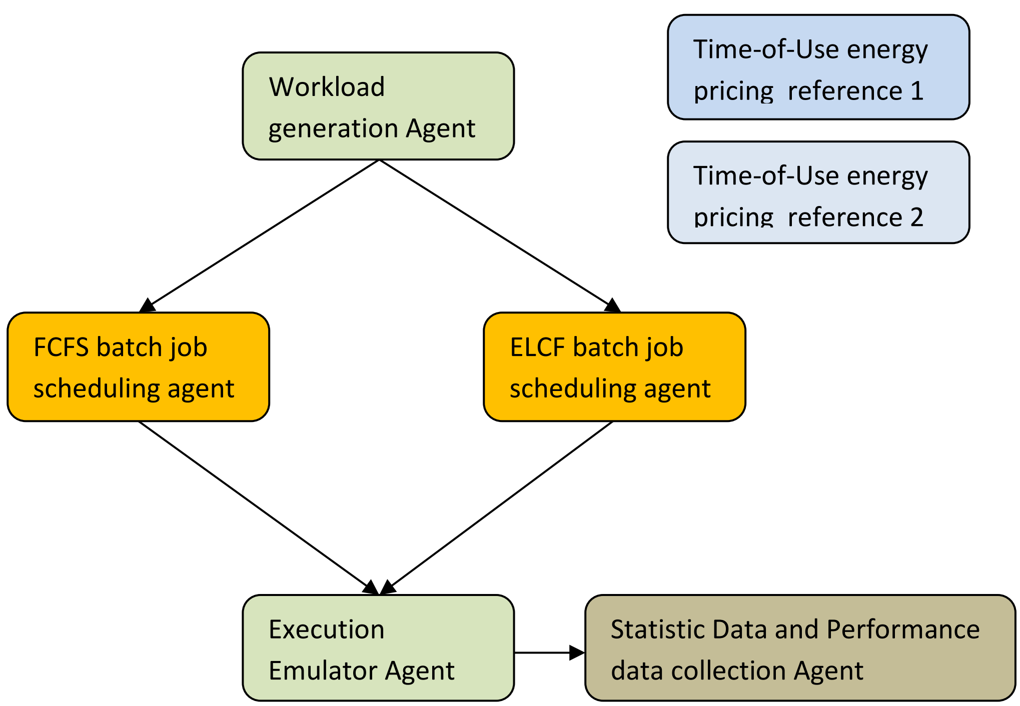

Figure-1: Processing Flow of Agents

3.2 Time-of-Use (TOU) Energy Pricing Modes used in Simulation

TOU rates are based on the amount of energy customers' use and when customers use it. Customer's rate will vary according to the time of day or night, and day of the week, and season of the year. Considering about the time of day customers use the most energy, or season of the year. Summer? Winter? Most low-rate periods are nights and weekends. Under TOU pricing, there are three different prices for three different periods:

- **On-Peak** is when electricity costs the most money.
- **Intermediate-Peak**, prices are slightly lower.
- **Off-Peak,** prices are the lowest.

Generally Saturday, Sunday, and designated major holidays (New Year's Day, President's Day, Good Friday, Memorial Day, Independence Day, Labor Day, Thanksgiving, Christmas and Mondays following any of those holidays that fall on a Sunday) are always considered Off-Peak periods by most of energy suppliers and energy distributers.

In this project, I used two TOU energy-pricing models. The first energy-pricing model is referenced from Ontario Electricity (Ontario, Canada) which representing the northern region [3][8]. The second energy-pricing model is referenced from Portland General Electricity which representing northwest region [4][9].

3.3.1 Time-of-Use Energy pricing model : Ontario Energy Board/Ontario Electricity, Canada

Ontario Electricity (ONE) uses time of use energy pricing model. Table 1 - Table 5 illustrate pricing rules for On-Peak, Mid-Peak, Off-Peak time sectors of ONE.

Ontario Electricity, Ontario, Canada	Winter: May 1st to October 31st Weekdays	Summer: November 1st to April 30th Weekdays	Weekend and Holidays
ON-Peek	7AM to 11AM 5PM to 7PM	11AM to 5PM	None
Mid-Peak	11AM to 5PM	7AM to 11AM 5PM to 7PM	None
Off-Peak	7PM to 7AM	7PM to 7AM	Whole day

Table 1: OE's Time sectors for On-Peak, Mid-Peak, and Off-Peak

Period	Cost cent/KW-hour	Color
Off-Peak	7.2 cent/KW-hour	Green
Mid-Peak	10.9 cent/KW-hour	Yellow
On-Peak	12.9 cent/KW-hour	Red

Table 2: OE's Energy Prices for each time sector

Winter 24 hour period	1	2	3	4	5	6	7	8
Weekdays	9	10	11	12	13	14	15	16
	17	18	19	20	21	22	23	24

Table 3: OE's Winter's weekdays 24 hours pricing chart

Summer 24 hour period	1	2	3	4	5	6	7	8
Weekdays	9	10	11	12	13	14	15	16
	17	18	19	20	21	22	23	24

Table 4: OE's Summer's weekdays 24 hours pricing chart

Weekend and Holidays	1	2	3	4	5	6	7	8
Saturday, Sunday, and Holiday.	9	10	11	12	13	14	15	16
	17	18	19	20	21	22	23	24

Table 5: OE's Weekend and Holidays 24 hours pricing chart

3.2.2 Portland General Electric - Time of Use Pricing

Portland General Electric (PGE) uses "Time-of-use" energy pricing model [4][9]. Table 6 - Table 13 illustrate pricing rules for On-Peak, Mid-Peak, Off-Peak time sectors of Portland General Electric.

PGE	**Winter: Nov 1st to April 30th**	**Summer: May 1st to Oct 31st**
ON-Peek	6AM to 10AM: Monday to Friday 5PM to 8PM: Monday to Friday	3PM to 8PM: Monday to Friday
Mid-Peak	10AM to 5PM: Monday to Friday 8PM to 10PM:Monday to Friday 6AM to 10PM : Saturday	6AM to 3PM: Monday to Friday 8PM to 10PM: Monday to Friday 6AM to 10PM: Saturday
Off-Peak	10PM to 6AM - Everyday 6AM to 10PM: Sunday and Holidays	10PM to 6AM: everyday 6AM to 10PM: Sunday and Holidays

Table 6: PGE's Time sectors for On-Peak, Mid-Peak, and Off-Peak

Period	Cost	Color
Off-Peak	4.048 cent/KW-hour	Green
Mid-Peak	6.967 cent/KW-hour	Yellow
On-Peak	12.142 cent/KW-hour	Red

Table 7: PGE's Energy Prices for each time sector

Winter 24 hour period	1	2	3	4	5	6	7	8
Weekdays	9	10	11	12	13	14	15	16
	17	18	19	20	21	22	23	24

Table 8: Winter's weekdays 24 hours pricing chart

Winter 24 hour period	1	2	3	4	5	6	7	8
Saturday	9	10	11	12	13	14	15	16
	17	18	19	20	21	22	23	24

Table 9: Winter's Saturday's 24 hours pricing chart

Winter 24 hour period	1	2	3	4	5	6	7	8
Sunday and Holidays	9	10	11	12	13	14	15	16
	17	18	19	20	21	22	23	24

Table 10: Winter's Sunday's and Holidays' 24 hours pricing chart

Summer 24 hour period	1	2	3	4	5	6	7	8
Weekdays	9	10	11	12	13	14	15	16
	17	18	19	20	21	22	23	24

Table 11: Summer's weekdays 24 hours pricing chart

Summer 24 hour period	1	2	3	4	5	6	7	8
Saturday	9	10	11	12	13	14	15	16
	17	18	19	20	21	22	23	24

Table 12: Summer's Saturday's 24 hours pricing chart

Summer 24 hour period	1	2	3	4	5	6	7	8
Sunday and Holidays	9	10	11	12	13	14	15	16
	17	18	19	20	21	22	23	24

Table 13: Summer's Sunday's and holidays' 24 hours pricing chart

3.3 Scheduling policy: two policies are implemented and compared in terms of energy cost spending and saving

Energy bill reduction depends on a number of factors, such as the type of business and the amount of energy customers’ use that can be shifted to a lower-cost period or spread over a 24-hour time frame.

3.3.1 First Come and First Server (FCFS) scheduling policy

First-Come-First-Served (FCFS) batch scheduling policy is used to arrange job-dispatching order based on job's arriving time only. It is a simple and easy solution. However it may not be an effective approach to reduce energy cost because it doesn't employ "Time-of-use" energy pricing information when job dispatching decision is made.

3.3.2 Energy Cost Aware Job Placement (ECAP) scheduling policy

In this approach, the job dispatching decision is based on a job's estimate energy cost and time-of-use energy pricing information from an energy supplier. Here are the heuristic approaches that I adopt in this policy.

- Instead of dispatching/scheduling an arriving job right away, we process a group of arriving jobs during a fixed time period (such as every one hour or every 30 minutes)
- Assigning an estimated energy consumption and cost of a giving job. A Job's energy consumption can be obtained from software profiling [5] or analytical approach [11].
    - estimated Energy Cost(job) = estimated power consumption(job) * estimated processing time(job)
- Classifying job's energy consumption in four categories: range is from less power consumption to very heavy power consumption. A reference table is as followed.

Power consumption	Range	Operation time
Category A	1kW/hour - 50kW/hour	Between 1 to 8 hours
Category B	50kW/hour - 100kW/hour	
Category C	100kW/hour - 250kW/hour	
Category D	250kW/hour - 500kW/hour	

Table 14: Job power consumption classification

- Set Power budget limit total time period, each time period
- This policy is to choose jobs whose aggregated power consumption will not exceed the power budget and to try to assign them to low cost time sector as many as possible. Instead of choosing jobs in a First come First served (FCFS) manner, it searches the waiting queue for an combination of jobs that can achieve the minimizing energy spending cost and do not break the power budget constraint.
- Dispatch jobs based on descending order of power consumption and estimate energy cost.
  - Assign jobs to next available Off-Peak time sector if power budget is not exceeding the limit.
  - Assign jobs to next available Mid-Peak time sector if Off-Peak power budget is reached.
  - Assign jobs to next On-Peak time sector if both Off-Peak and Mid-Peak power budgets are reached.
- Dispatch a job with 8 hour after it arrive
- Update job status and collect statistic and performance data
- To simplify the study and simulation program implementation, I only consider weekdays operation time. Extended operation time of weekends and holidays is not implemented in my simulation program

4 Testing RESULTS

After running many testing cases, I have picked four different workloads and used their testing data in this report. "Workload 1" and "Workload" are with 70%-75% system utilization. "Workload3" and "Workload-4" are with 85%-90% system utilization. “Workload 1” and “Workload 2” represent heavy workload runtime environment on data centers. “Workload 3” and “Workload 4” represent heavier workloads on data center daily processing activities. Those four workloads have been applied to both FCFS and ECAP scheduling policies. Simulation time is limited to 120 hours which is equal to five weekdays. Virtual time tick counter is used in NetLogo software to emulate the wall clock.

4.1 Workloads on Ontario Electricity energy pricing model

Figure-2 shows the energy cost spending on five weekdays time period (120 hours operation span). Figure-3 shows the normalized cost spending ration between FCFS and ECAP policies. Figure-4 shows the cost reduction rate from the ECAP scheduling policy.

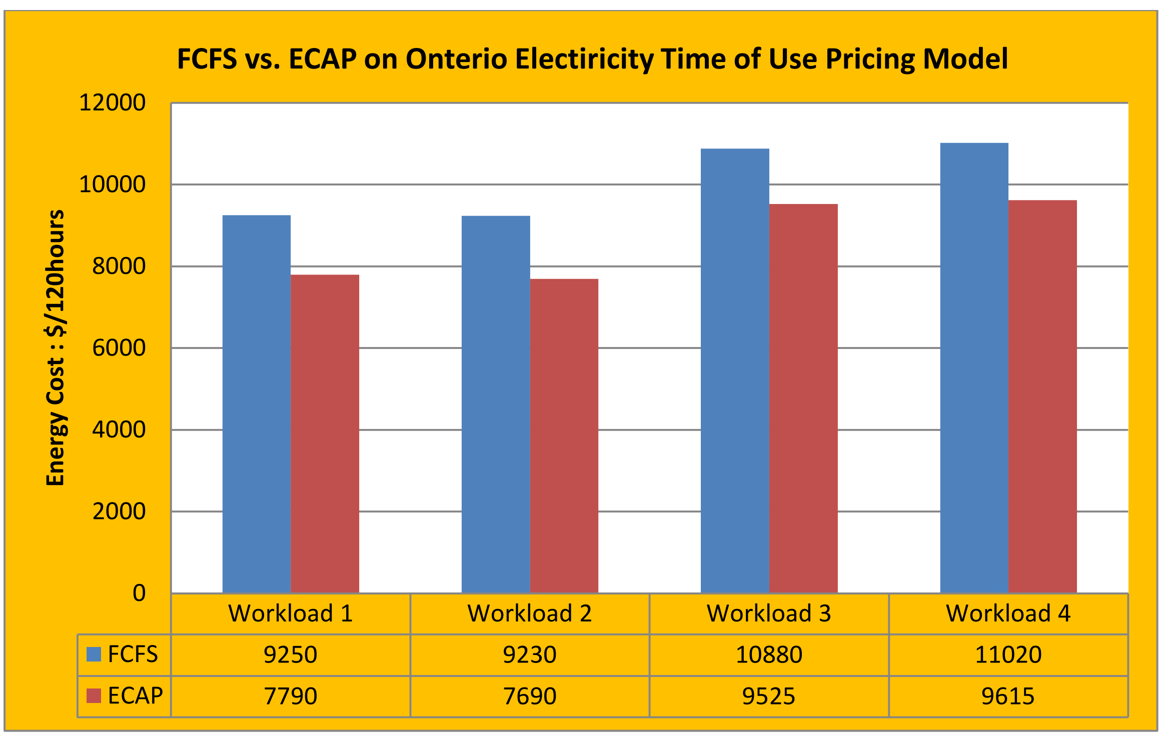

Figure 2: Energy cost spending on Ontario Electricity pricing model

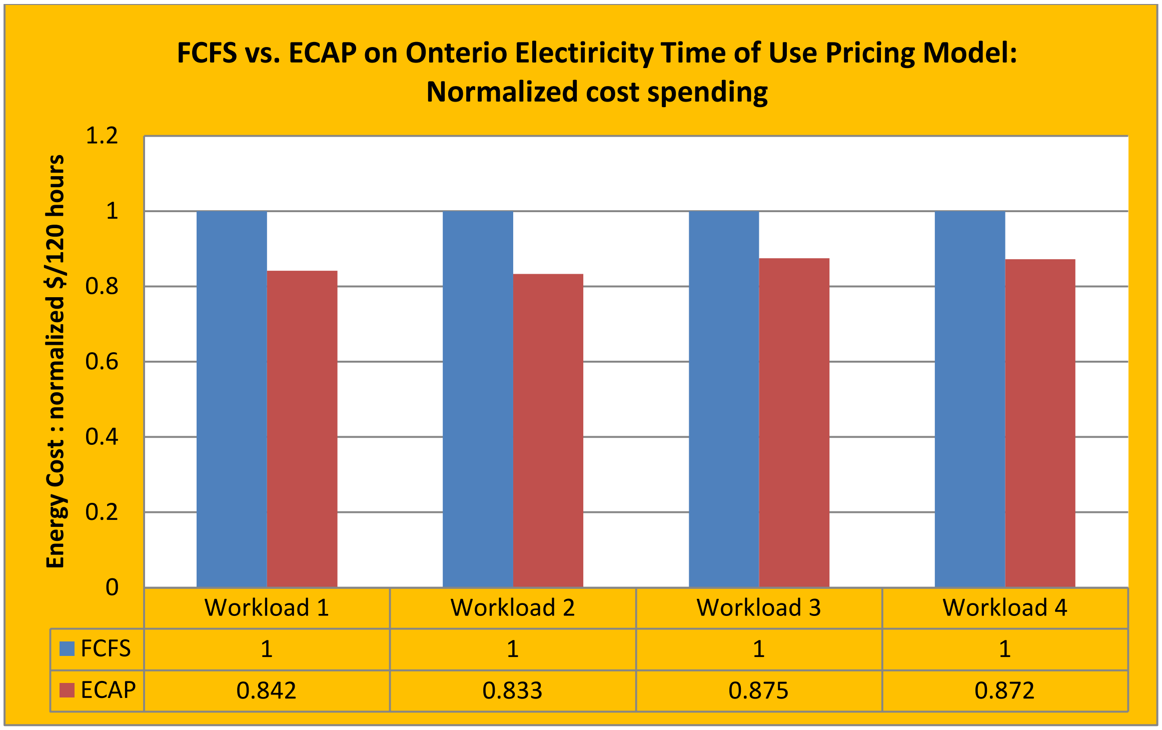

Figure 3: Normalized cost spending ration FCFS vs. ECAP on Ontario Electricity pricing model

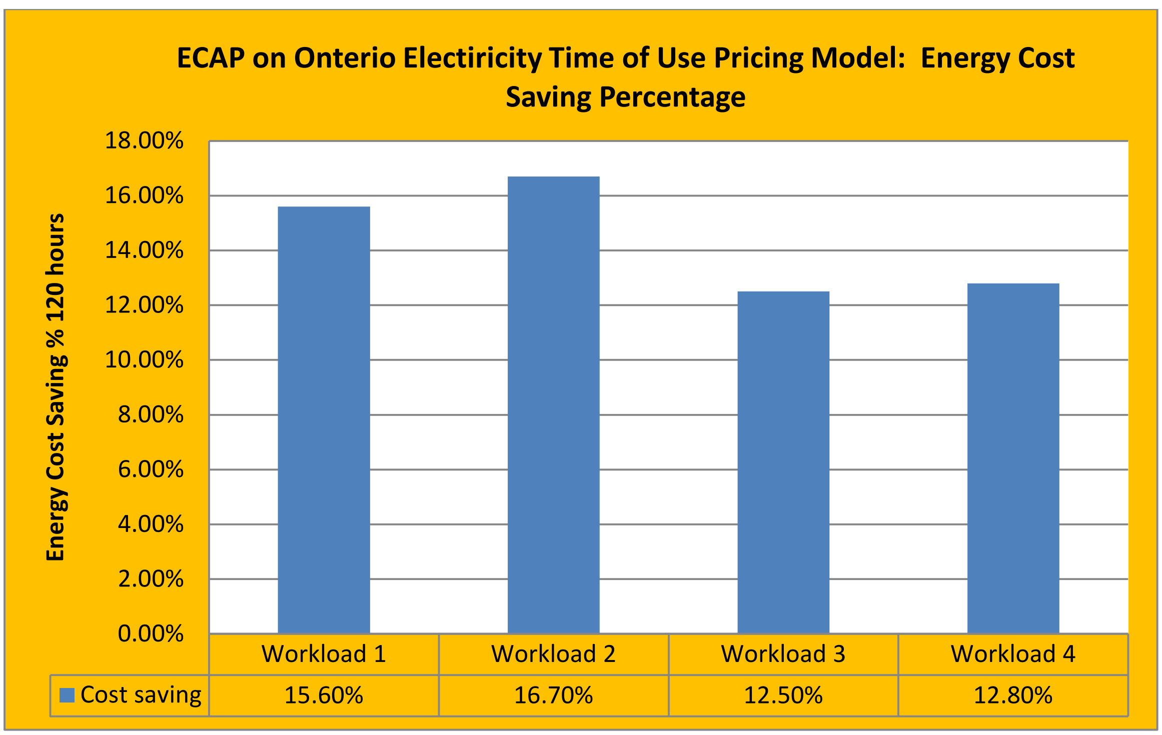

Figure 4: ECAP energy cost reducing ratio on Ontario pricing model

4.2 Workloads on Portland General Electric energy pricing model

Figure-5 shows the energy cost spending on five weekdays time period (120 hours operation span). Figure-6 shows the normalized cost spending ration between FCFS and ECAP policies. Figure-7 shows the cost reduction rate from the ECAP scheduling policy.

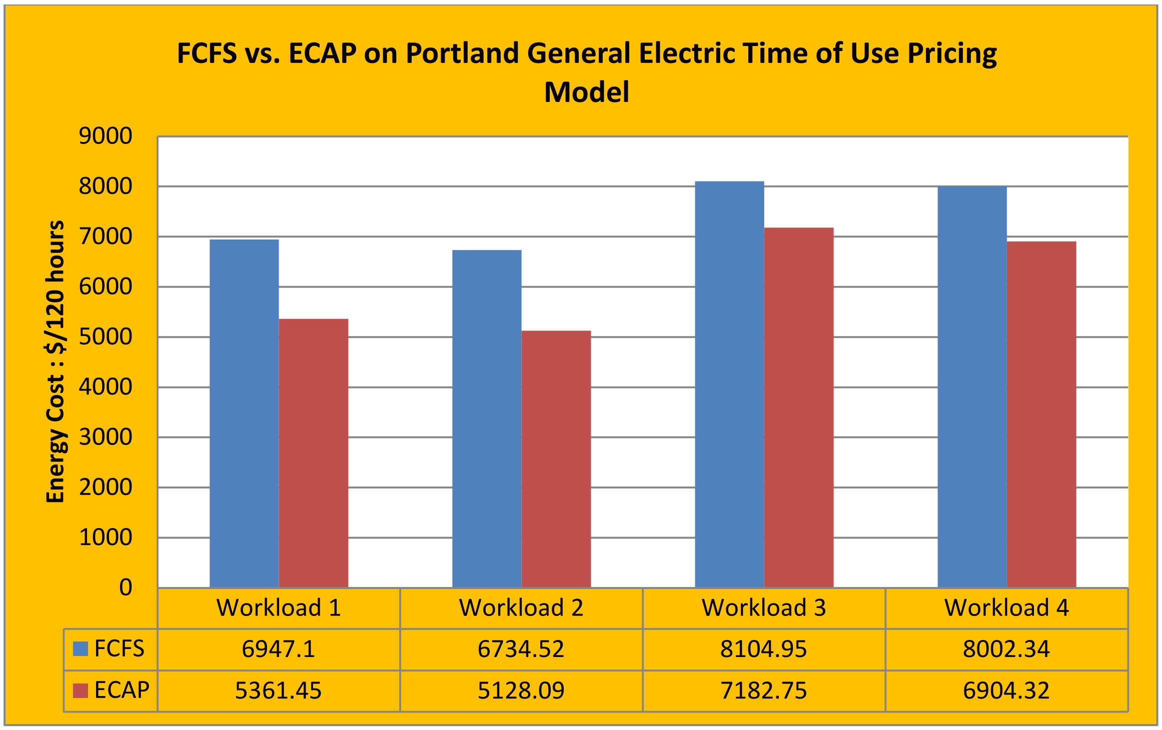

Figure 5: Energy cost spending on Portland General Electric pricing model

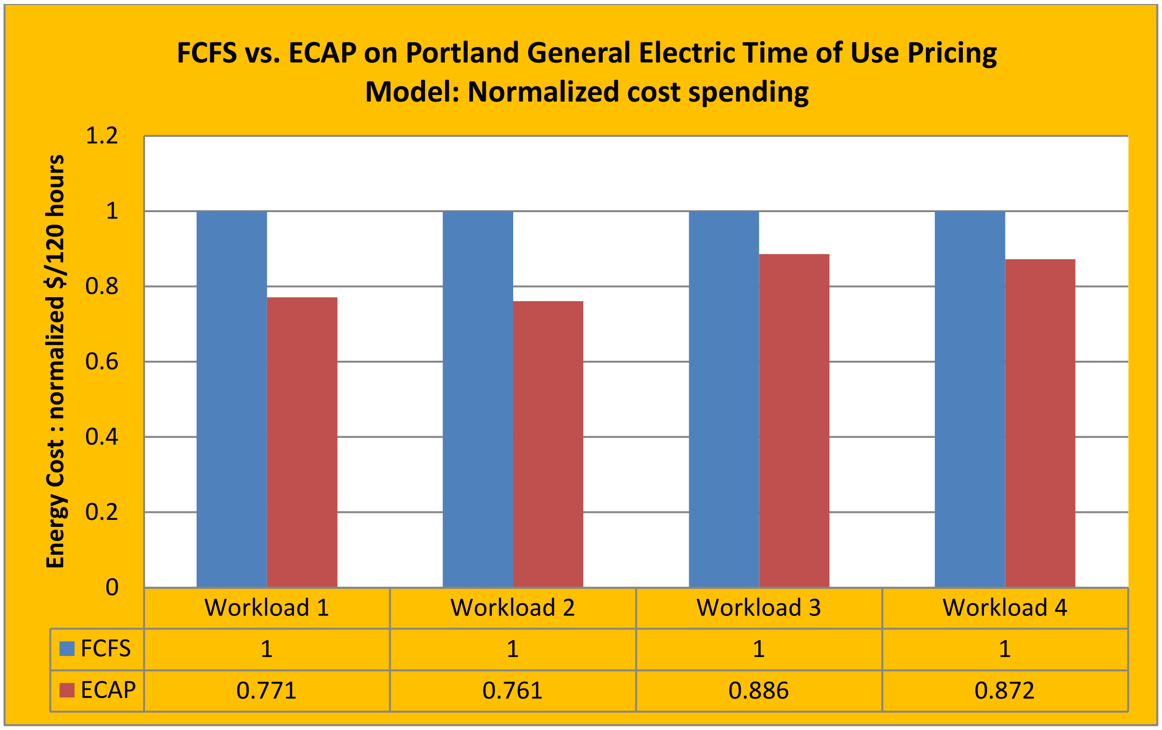

Figure 6: Normalized cost spending ration FCFS vs. ECAP on PGE pricing model

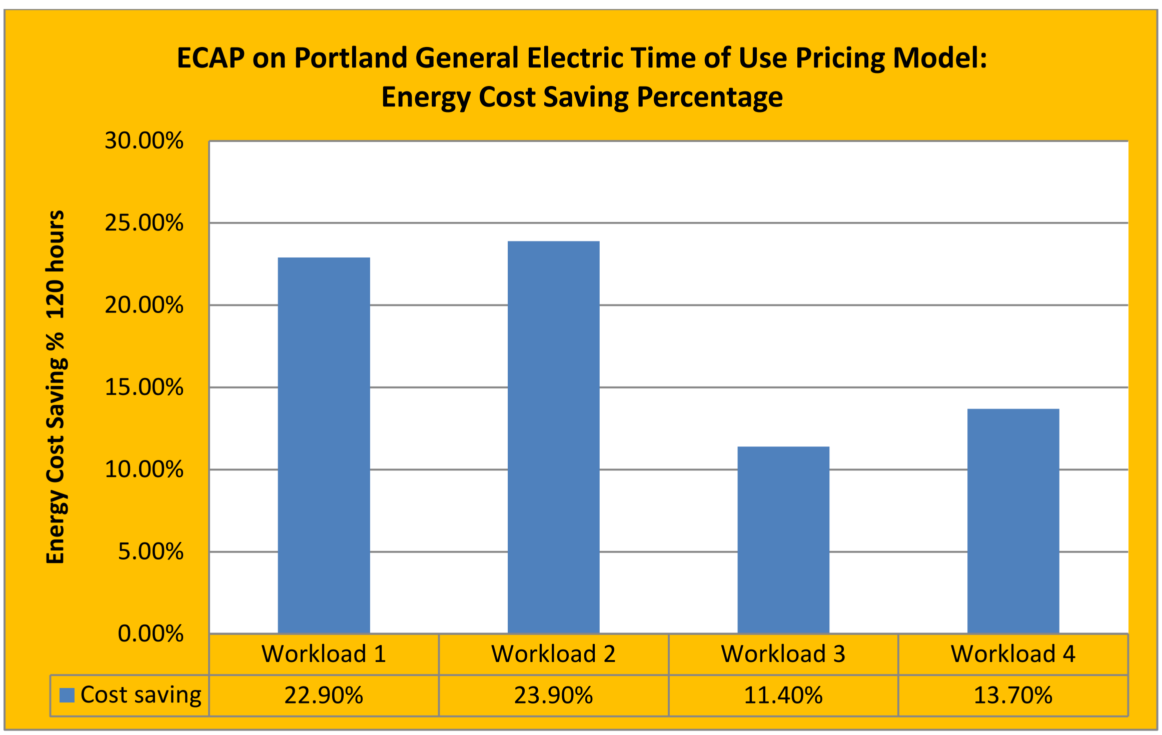

Figure 7: ECAP energy cost reducing ratio on PGE pricing model

4.3 Discussions

The time sector ratio of On-peak, Mid-Peak, and Off-Peak in Ontario Electricity (ONE) is "6 : 6 : 12". 50% of time slot is allocated for Off-Peak time sector. When under the situations of 70%-75% and 85%-90% system utilization, Off-Peak time sector has been used close to 100% on all four different workloads. The remaining jobs with less power consumption were allocated to Mid-peak and On-peak time sectors. The results from Fugure-3 and Figure-4 have clearly reflected this observation. The energy price reduction rates are close on all four difference workloads.

In Portland General Electric (PGE) energy pricing model, the time sector ratio of On-peak, Mid-Peak, and Off-Peak is "7 : 9 : 8". Each time sector has close time slot allocation. Also the price gap between time sectors in PGE's pricing model (On-Peak:Mid-Peak:Off-Peak = 2.75 : 1.72 : 1) is bigger when compared to the ONE's pricing model (On-Peak:Mid-Peak:Off-Peak = 1.79 :1.51 : 1). When a heavy workload is applied to PGE pricing model, in ECAP policy, the simulation has shown that ~44.4% power consumption goes to the Off-peak time sector, ~50% power consumption goes to the Mid-Peak time sector, and only ~5.6% power consumption goes to the On-Peak time sector. In FCFS policy, the simulation has shown that power consumption ratio is 29.1% vs. 37.5% vs 33.3% for On-Peak vs. Mid-Peak vs. Off-Peak. Because more power consumption are allocated to Off-Peak and Mid-Peak time sectors in ECAP policy, Figure 6 and Figure-7 have shown the reason why ECAP policy can reduce more energy cost on PGE's pricing model.

When heavier workloads were applied, the impact of ECAP scheduling policy has become less significant because most of time sectors were used and it was approaching the results from using FCFS scheduling policy. The results of “Workload-3” and “Workload-4” in Figure-4 and Figure-7 present this evidence.

Testing results also show that overall the ECAP policy can reduce 12.5% to 16.7% energy cost in ONE pricing model and can reduce 11.4% to 23.9% energy cost in PGE pricing model. The proposed ECAP policy has demonstrated as a better batch job scheduling policy because it has considered “Time-of-Use” pricing model in job placement decision.

5 Conclusions

Energy-related costs have become one of the major economic factors in today's data-centers and companies. The research community is currently working on new efficient power-aware resource management strategies. The motivation behind this energy cost reduction study is that it provides insight into energy consumption patterns and job scheduling policies in data centers and HPC facilities. The proposed ECAP batch job scheduling policy is a heuristic approach. It helps in verifying if an intelligent and simple batch job scheduling policy design can meet its power constrain and further reduce energy cost. This can also be used to guide the design of more complicated resource management software such that it can be efficiently and effectively applied to real world computing systems. The principal contribution is the study of power consumption problems and the investigation of energy cost reduction approaches.

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