Software Based Power Meter for Data Centers

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Abstract

In the era of cloud computing, data centers have emerged as possible solutions, without which a lot of our daily work could not function properly. Modern data centers consist of various components such as, communication and storage equipment, power supplies, air conditioning (HVAC) equipment and monitoring systems etc. Power plays a critical role in the data center. Because of the high demand for uninterrupted services, many data centers are equipped with redundant power supply units and backup systems. The main goal of our project is to measure the power of individual servers from the server rack in a data center. But without using a conventional power meter, we are using a different approach which utilizes the high-frequency switching operation (40 to 100 kHz) of the power factor correction circuit universally built in today's server power supply units(PSU). By using DNN we have tried to separate the mixed signature of all servers in a rack and then use the notion of PFC circuit to estimate the power of individual servers.

1 Introduction

Today's data centers consume huge amounts of power. Facilities-based in the United States alone consumed over 90 billion kilowatt hours of electricity in 2017 and industry growth trends show no signs of slowing.For organizations colocating equipment in a carrier-neutral facility, data center power management can mean quite a lot. They not only have an impact on pricing, but also can greatly affect IT deployments. Data center customers need to understand their own power needs in order to take advantage of the efficiencies offered by colocation facilities [1].

In a data center there are several locations where power can be measured. Moving from the coarsest measurement to the most detailed the first is the power entering the data center. If the data center is a stand-alone structure this is simply the power feed from the utility. The next place where power is often measured is at the UPS. But UPS power monitoring can not give a detatiled look of the server level power consumption. A third place to measure power is at the rack itself with metered rack PDUs. A fourth place to measure power is at the individual outlets of a rack PDU. These intelligent PDUs also typically provide aggregated rack power consumption as well. But Intellegent based PDU (iPDU) can costs thousands of dollars [2].

To overcome this issue we discover a novel physical side channel — voltage side channel — which leaks information about benign tenants' power usage at runtime. Concretely, we find that a power factor correction (PFC) circuit is almost universally built in today's server power supply units to shape server's current draw following the sinusoidal voltage signal wave and hence improve the power factor (i.e., reducing reactive power that performs no real work). The PFC circuit includes a pulse-width modulation (PWM) that switches on and off at a high frequency (40 - 100kHz) to regulate the current. This switching operation creates high-frequency current ripples which, due to the Ohm's Law (i.e., voltage is proportional to current given a resistance), generate voltage ripples along the power line from which the server draws current [3]. Importantly, the high-frequency voltage ripple becomes more prominent as a server consumes more power and can be transmitted over the data center power line network without interferences from the nominal grid voltage frequency (50/60Hz).

We created a benchmark to test on different power supply unit (PSU) to check the relationship between consumed power vs power spectrum density (PSD). We found out that there is a direct correlation between consumed power and commulitive PSD. Then we tried to figure out the regression model to find consumed power from the frequency domain components of voltage signal at very high frequency. Then we lead our research to next level finding the power spectrum pattern of PSU in mixed condition i.e. while two PSU is presents. This time this pariticular problems has become much complex with source separation first and then regression based problem for finding power consumed by each PSU. We have done Non Negative Factorizarion (NMF), Independent Comonent Analysis (ICA), Principle

34th Conference on Neural Information Processing Systems (NeurIPS 2020), Vancouver, Canada.

Component Analysis (PCA) in our mixed data signal. We generated this data by runnind two different servers at the same time with our benchmark. So the dataset represents the same power consumption in data centers. We found out NMF perform better for our dataset to separate the sources from mixed signal. In our next stage we will discuss the method, result and conclusion.

2 Method

2.1 Data center Power Infrastructure

In a typical multi-tenant data center as illustrated in Fig. 1, utility power first enters into a centralized UPS through an automatic transfer switch (ATS). Then, the UPS feeds protected power (also called critical power) into multiple PDUs, each supporting a few tens of racks that are connected to tenants' servers. Our goal is to find out power consumption by each racks in the PDU [4].

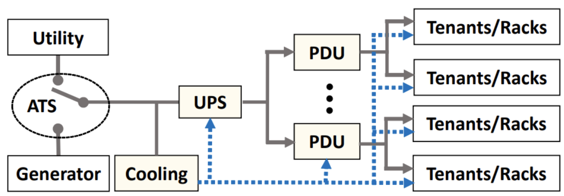
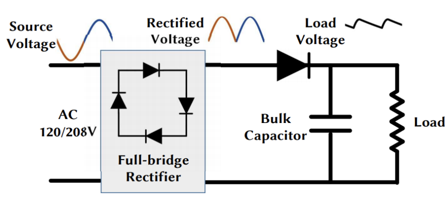


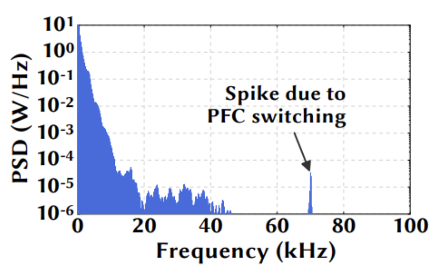
Figure 1: Data center infrastructure.

2.2 PFC ciruit in Power Supply Unit

A power factor correction (PFC) circuit reduces the harmonic distortion in the supply current and creates a current waveform close to a fundamental sine wave in order to increase the power factor to unity.The PFC works by inducing a current in the inductor and causing the current to track the input voltage. The control circuit senses both the input voltage and the current flowing through the circuit. The switching frequency of pfc circuit is very high (40-100kHz). As we can see in the picture, In a vey high frquency around 70kHz, we see a spike due to the switching frequency of the pfc circuit. So we have used high pass filter to filter out only the pfc signature and tried to find out the realtionship of the spike with power consumption.



(a) PFC circuit principle

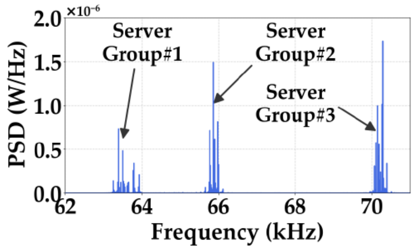


(b) Sprike Due to PFC switching

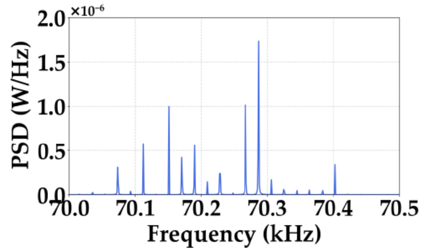
Figure 2: PFC circuit in Power Supply Unit (PSU)

2.3 PDU level power spikes

We also identify that, due to the feedback based design, the PFC switching frequency of the server power supply units does not need to be tightly controlled. The PFC switching frequency varies even for servers purchased in the same batch from the same vendor, let alone servers of different generations 3(a). We can clearly see that different generations create distinctly different power spikes at different frequencies. Moreover, as shown in Fig. 3(b), we can even identify the PFC spikes from different servers within the same generation. These results provide us the second important insight that the power consumption signature generated by the PFC circuits can be separated for each server.



(a) Spikes due to 3 batches of servers



(b) Sprike inside same batch

Figure 3: Feasibility of separating Spikes within same batch

2.4 Dataset

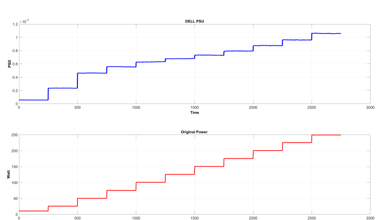
We have generated our dataset by running our own benchmarks in actual servers in our lab. We have used 2 different servers with multiple PSUs and run our experiment to see how the spike of two servers are mixed in the frequency spectrum. We collected the data having known the actual power consumption by each server as ground truth. We have used Tektronix PA3000 power analyser and Tektronix MSO51 5 series Oscilloscope.

Figure 4: Generating Dataset using different PSU

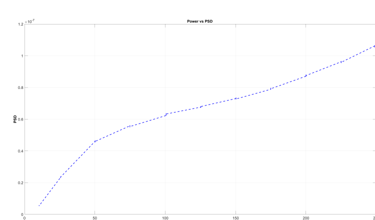
3 Result

3.1 Experiment on single Server

For feasibility analysis of our model, we run our experiment on DELLl PowerEdge server with 750W power supply unit. Then we ran our benchmark in that servers. This benchmark can increase and decrease power consumption of server in a regular manner. We than get the voltage spectrum from any outlet by using Tektronix MSO51 5 series Oscilloscope.. We keep track of the actual power by using Tektronix PA3000 power analyser. Then by using a high pass filter, we were able to separate out the spike in the frequency domain. Using Commulitive PSD Algorithm, we compare it with actual power consumption. We found a very high correaltion, around 97 % and the relationship is not linear. The analysis is shown in the figure below.



(a) Actual power vs Aggregated PSD



(b) Relationship between Power Vs PSD

Figure 5: Relationship between Power Vs Aggregated PSD

As we can see from the figure, the left side figure, we plot real cosumed power vs sum of PSD spikes, we can see the shape of the signal correlates with each other even though their values is much smaller compared to actual power i.e.

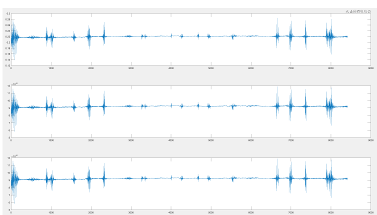
in micro watt range. Then we try to figure out the relationship between them, as you can see in the right figure, the relationship is not linear.

3.2 Experiment on Two servers

In this particular case we tried to see the behavior in votage intrution signal when two servers are taking power from same PDU. When two servers are running in the system, the probleem no longer remains a regression model rather it becomes a source separation problem. Since in the voltage signal the signature of the two servers remain side by side having an interference between them, we need to separate the mixed signal first, then go for mapping about their consumed power.

We have run our benchmark in both the servers, i.e. the benchmark actually vary the power with 6 different stable power stages from 137W to 240W for each server. We took all the combination of power mixture between these two servers for a long period of time for our data set. In the same time we also monitor the power consumption of each individual servers for ground truth.

For source separation of two mixed signals we have choose the Non Negative Factorization(NMF). But the separation is liitle bit complex, since the signature of two server is almost identical and they don't have much statistical differences. So most of the available techniques for sound source separation fails for separating this type of particular Mixed signal.



```
6000/6000 [==============================] - 0s 40us/sample - loss: 0.3041 - acc: 0.8628
Epoch 993/1000
6000/6000 [==============================] - 0s 41us/sample - loss: 0.3105 - acc: 0.8582
Epoch 994/1000
6000/6000 [==============================] - 0s 42us/sample - loss: 0.3014 - acc: 0.8677
Epoch 995/1000
6000/6000 [==============================] - 0s 41us/sample - loss: 0.2871 - acc: 0.8703
Epoch 996/1000
6000/6000 [==============================] - 0s 41us/sample - loss: 0.3013 - acc: 0.8675
Epoch 997/1000
6000/6000 [==============================] - 0s 40us/sample - loss: 0.2974 - acc: 0.8665
Epoch 998/1000
6000/6000 [==============================] - 0s 40us/sample - loss: 0.2959 - acc: 0.8633
Epoch 999/1000
6000/6000 [==============================] - 0s 42us/sample - loss: 0.2967 - acc: 0.8652
Epoch 1000/1000
6000/6000 [==============================] - 0s 40us/sample - loss: 0.2823 - acc: 0.8688

Test accuracy: 38.2%
```

```
6000/6000 [==============================] - 0s 19us/sample - loss: 0.8017 - acc: 0.6692
Epoch 993/1000
6000/6000 [==============================] - 0s 19us/sample - loss: 0.8036 - acc: 0.6687
Epoch 994/1000
6000/6000 [==============================] - 0s 19us/sample - loss: 0.8047 - acc: 0.6627
Epoch 995/1000
6000/6000 [==============================] - 0s 20us/sample - loss: 0.8059 - acc: 0.6753
Epoch 996/1000
6000/6000 [==============================] - 0s 20us/sample - loss: 0.8142 - acc: 0.6665
Epoch 997/1000
6000/6000 [==============================] - 0s 20us/sample - loss: 0.8239 - acc: 0.6605
Epoch 998/1000
6000/6000 [==============================] - 0s 19us/sample - loss: 0.8075 - acc: 0.6742
Epoch 999/1000
6000/6000 [==============================] - 0s 19us/sample - loss: 0.7966 - acc: 0.6738
Epoch 1000/1000
6000/6000 [==============================] - 0s 19us/sample - loss: 0.7989 - acc: 0.6683

Test accuracy: 42.3%
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Figure 6: Seperation of two sources from mixed source by NMF (left), Trainig and testing the sepated signal using Deep learining based Logistic Regression

After separating the mixed signal using NMF, we tried both Independent Principle Analysis (ICA) and Principle Component Analysis (PCA) for reducing the number of extra features in the signal. After removing the noise from the signal, We train the model using ANN based Logistic Regression with hot encoding. For the ANN we used a batch size of 128, dropout of 0.45 and the number of nodes were 512 for training purpose. After we separated the mixed signal by NMF, we trained the model with two separated sources. The training and testing accuracy for both sources are plotted in following figure. From the Figure 6 we see that the training accuracy for source 1 is around 87 percent but the testing accuracy is around 40 percent and for source 2, the training accuracy is around 65 percent while the testing accuracy is 45 percent. For both cases the training were quite good, but testing does not show that NMF based approach is the good one. One reason of this result is, because of two sources from same class, it was quite hard for unsupervised learning like NMF to capture the right permutation of the two sources.

4 Conclusion

We found a novel way of monitoring power consumption of servers in data center. We have used voltage side channel as a way of intrution and only monitoring single point voltage signal lead us to find out the way of getting power consumption of servers. But the proposed NMF based idea is not capable of capturing two sources of same class. So we will lead our problem to next level to separate the sources using Autoencoder/LSTM baseed model in future and compute power consumption for multiple servers case just like actual data center.

References

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[3] Mohammad A. Islam, E. & Shaolei Ren, E. (2018) Ohm's Law in Data Centers: A Voltage Side Channel for Timing Power Attacks. *IIn Proceedings of the 2018 ACM SIGSAC Conference on Computer and Communications Security (CCS '18).* 10.1145/3243734.3243744

[4] Mohammad A. Islam, E. & Shaolei Ren, E. & Adam Wierman E. (2017) Exploiting a Thermal Side Channel for Power Attacks in Multi-Tenant Data Centers. *In Proceedings of the 2017 ACM SIGSAC Conference on Computer and Communications Security (CCS '17).* 10.1145/3133956.3133994