Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 1 (2025)

Hedging Basis Risk in Power Portfolio Using Principal Component Analysis

Ritesh Kumar,

Energy Risk Researcher, Department of Finance / Energy, Middle Georgia State University

Corresponding email: ritesh061176@gmail.com

Article History:

Received: 12-01-2025

Revised: 15-02-2025

Accepted: 01-03-2025

Abstract:

There has been many studies about hedging power prices but most of them are limited to Power price at hub. This paper studies the Basis Risks in power portfolio more specifically it explain the Basis Risks present in a Power portfolio, the limitations of hedging these risks and develops a framework to hedge the Basis Risk using Principal Component Analysis framework.

Keywords: Principal Component Analysis, Basis Risks, Power portfolio , PJM Portfolio, Electricity

1. Background

Unlike financial markets, Power markets are highly locational because the production of electricity happens at one geographical location and consumption takes place at another geographical location. Power is even more complicated because unlike gas, it can’t be stored and needs to be transmitted instantaneously. In a given ISO, there are thousands of generation and consumption points and it is not possible to have sufficient liquidity at each of these thousands of locations; this has lead to emergence of concept of “Hubs” and “Zones” which are representative of several generation/ consumptions points within a particular geography. The trading for all these generation/consumption points is done at the Hub and/or Zone. These Hubs and Zones are liquid enough for market participant to take position but then it leads to Basis Risks between the generation/consumption point and the corresponding Hub/Zone.

Most trading shops, merchant generators and utilities have a portfolio spread out within multiples zones within an ISO. If there is a merchant generation, then most likely it has generation assets located in multiple zones. Similarly, if there is a load serving utility then most likely it serves load across multiple zones. These entities hedge their exposure at the liquid Hub / Zones and then they are exposed to Basis risks.

There have been some studies about hedging power risks using energy futures and forwads but most of them are limited to Hubs / Zones (BystrÖm, 2003; Zanotti & Gabbi & Geranio, 2010; Hanly &

Morales & Cassells, 2018). Power portfolio do have substantial Basis Risk and the purpose of this paper is to explain these risks and propose a model to hedge Basis Risks in power portfolio.

Most of the portfolio managers are "Basis Takers" i.e. they don't do anything to hedge the Basis position. The primary reason for this is the illiquidity of Basis. Even if some market participants are willing to sell the basis, the Bid-Ask spread is very large which makes the economics of hedge unattractive. Also, if a Basis position is being offered, then there is not large enough offer (MWs).

In some cases, portfolio managers don't bother to hedge the Basis Risks because the "Forward Value" is low. But if the month witness extreme weather events, then Basis can explode or implode leading to huge large $ impact. This impact can be so large that it can drive entities to bankruptcy and we have enough evidence of this within United States.

2. Drivers of Zonal Basis

The Basis is stochastic and is a function of several grid parameters.

2.1. Difference between Load and Generation within the Zone: If the Generation within a Zone is enough to serve the load within the Zone then the Basis is not large. But if there is a mismatch between load and generation is large, Basis starts to increase. If an extreme weather event has happened e.g. extreme hot or cold, then zone has to procure power from other zones and most likely from non-economical units leading to increase in Basis. Similarly, say if the zonal load drops drastically then the zone will have excess generation leading to large drop in Basis.

2.2. Transmission Infrastructure: If the transmission infrastructure is not sufficient to transmit the power from source to sink then it leads to congestion in the grid. In such a scenario, the more expensive units within a zone have to come online to meet the load obligation leading to large Basis.

2.3. Supply Stack: Supply Stack can impact Basis in multiple ways:

- If generation units in a zone are old and are susceptible to trips / unplanned outage then any outage of such plants, will cause mismatch in load and generation and an increase in Basis.
- If the supply stack is heavily composed of intermittent generation like Solar / Wind / Hydro/ Battery then it can impact the Basis. The Wind/ Solar Generation is stochastic and if they underproduce or overproduce then it can lead to mismatch in load and generation leading to large swings in Basis.

3. Power Portfolio Basis Risks

If a power portfolio has exposure to one or two Basis then things are not as complicated. May be the portfolio manager manages to find a counterparty which can sell the Basis MWs. The problem arises when portfolio is exposed to many basis which leads to "Basis Portfolio". In these situations, it is difficult to find counterparty and large MWs at each Hub / Zone to hedge at a reasonable price. Consider a hypothetical load portfolio within PJM ISO wherein the load is distributed across multiple zones including PEPCO, DPL, PENELEC, PSEG, BGE, ATSI, DOM, BGE and each Zone has a different amount of load. If the portfolio manager tries to hedge each of the Zones, it is nearly impossible to do it. So the portfolio manager puts on hedge at the hub level i.e. "PJM West" because PJM West is the most liquid hub. The total MWh at the PJM West is the sum of the positions at each of the zones i.e. 417.1 GWh. After putting on this position, this portfolio has Basis exposure and the Basis is from each of the eight zones viz. PEPCO, DPL, PENELEC, PSEG, BGE, ATSI, DOM, BGE and from PJM West.

Power Portfolio (MWh) for Jan delivery

	Load Exposure	Hedge	Basis Exposure
PEPCO	(72,634)		(72,634)
DPL	(91,989)		(91,989)
PENELEC	(41,751)		(41,751)
ATSI	(36,303)		(36,303)
DUQ	(45,107)		(45,107)
COMED	(54,556)		(54,556)
DAYTON	(46,458)		(46,458)
NI HUB	(28,349)		(28,349)
PJM West		417,147	0

4. Model for Basis Hedging:

Principal component Analysis is great tool to reduce dimensions (Kambhatla & Leen, 1997). This paper employs the Principal Component Analysis (PCA) framework to hedge Basis Risks. The exposure at each Basis location is assumed to be a dimension and so a portfolio is assumed to be composed to many dimensions. PCA is used to reduce the dimension and we are left with one or two dimensions which represents the most amount of variation in the portfolio. If we hedge these first principal component (PC1) and/or second principal component (PC2), we can hedge most of the variation in the portfolio. The model essentially consists of three steps a) Simulate Basis b) Perform PCA analysis c) Hedge the PCs.

1. ***Simulate Zonal Basis:*** There are different methodologies for simulating the Basis. One such approach is to do a bottom's up approach wherein the temperature, load, generation and price are simulated for each point in an ISO and Basis can be computed from this. The other way is to use the historical data to simulate the Basis. This is a quick and fairly accurate way to simulate Basis because all the grid conditions including weather swings, load swings, plant outage, transmission outage is baked into the historical data. This historical data also readily available from the ISO. Another source of this information is the FTR/CRR auction published by the ISOs. Most of the ISOs, computes "Shadow Pricing" wherein they determine price at all points on the grid. The result from these auctions can be used to compute Basis.

2. ***Perform PCA***: Basis is composed of Congestion and Loss. Losses are usually fixed, is a function of transmission infrastructure within an ISO and are usually a fixed percentage of the electricity price. These losses can be backed out from Basis to imply the congestion which is the stochastic component. This congestion is a function of different factors including load swings, plant outage, generation variability, transmission outage etc. But if the ISO is expected to have major upgrades / changes to supply stack and / or transmission infrastructure then the same has to be reflected into the congestion. A correlation matrix is computed using a historical congestion and PCA analysis is performed on this.

3. ***Hedge Basis***: Once PC1 and PC2 has been determined then we have to find an appropriate hedge instrument to hedge these PCs. Since PC1 and PC2 are independent, the hedge instruments should be different for each of these. Also, the hedge instrument should be correlated with PCs and should have the same volatility as the PCs.

5. Data

For the purposes of this study, PJM market was chosen because there are several zones within PJM market, the liquidity at each zone is relatively low and but there is a liquid hub PJM West.

The PJM ISO is well suited for Basis study also because the generation and load are not usually co-located in the same zone in PJM. Often times, the generation and load are located in different zones which calls for power to be transmitted over large transmission line from source (generation) to sink (load) leading to congestion and a blow up in basis.

Lastly, PJM ISO is located in North East region in United States and is exposed to extreme weather conditions especially in Winter leading to large swings in Basis.

For purposes this study Jan 2023 and Feb 2023 was chosen. Historically the Basis spikes have happened during 7x16 block, but it has been assumed that Basis spikes would happen only during 5x16 block. The historical years for study are 2019 through 2022 and it has been tested using 2023 data.

Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 1 (2025)

The portfolio is composed of Load in several Zones viz. PEPCO, DPL, PENELEC, DAYTON, NI HUB, ATSI, DUQ & COMED and is assumed to be fully hedged using PJM West Hub leaving with Basis exposure. It has also been assumed that there is enough liquidity for PJM West about three months in advance and that hedges are put on around this time. This timeframe has also been chosen because by this time, the market has a fairly good estimation of how Winter will pan out and this information is baked into the forward market. Market also has a good estimate of supply stack and any transmission upgrades that will happen about three months later. Because of this information, the Basis prices for Winter months are fairly accurate and it is a good time to put on hedge.

6. Results

The PCA analysis and Hedge details for Jan 2023 and Feb 2023 are presented below. As shown in the first table below, PC1 explains ~ 69% of Basis variation while PC1 and PC2 combined together explain about 84% of variation in Basis.

The second table shows the $ impact of Basis move, Hedge MtM and the hedge effectiveness for January 2023. The first column shows the $ impact of Basis move using the both components of Basis viz. congestion & Fees while the second column shows the $ impact using only the congestion component of Basis. The Hedge MtM is positive showing that, the hedge moves opposite to Basis. The table also shows the effectiveness of the hedge using $ impact of both kinds of Basis move .

PCA Analysis for January

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
WEST	0.3730	0.0410	-0.1306	0.5563	-0.1901	-0.6531	0.2364	-0.0049	0.1189
PEPCO	0.3990	0.0497	-0.0587	-0.0130	0.0146	0.2908	-0.1880	-0.4696	0.7029
DPL	0.3435	-0.2716	0.1282	-0.6205	-0.5250	-0.0982	0.3460	0.0415	-0.0048
PENELEC	-0.3772	-0.1857	0.1736	-0.2825	0.0181	-0.6309	-0.4676	-0.1901	0.2451
DAYTON	-0.3998	0.0587	0.0232	-0.0076	0.0313	0.0239	0.4262	0.4810	0.6493
NI.HUB	-0.3992	0.0729	-0.0109	0.0059	0.0126	-0.0274	0.5637	-0.7126	-0.0935
ATSI	0.1859	-0.7008	0.3080	0.1057	0.5702	0.0014	0.2071	-0.0072	0.0099
DUQ	-0.2918	-0.5299	0.0158	0.4279	-0.5850	0.2776	-0.1676	-0.0456	0.0344
COMED	0.0501	0.3268	0.9149	0.1764	-0.1386	0.0527	-0.0090	-0.0181	-0.0053
Std Deviation	2.4928	1.1519	0.9961	0.5618	0.3310	0.1848	0.0702	0.0432	0.0283
Variance	6.2141	1.3268	0.9922	0.3156	0.1095	0.0342	0.0049	0.0019	0.0008
Cum Variance	6.2141	7.5409	8.5331	8.8487	8.9582	8.9924	8.9973	8.9992	9.0000
Ind. Var. Expln.	69.05%	14.74%	11.02%	3.51%	1.22%	0.38%	0.05%	0.02%	0.01%
Cum Var. Expln	69.05%	83.79%	94.81%	98.32%	99.54%	99.92%	99.97%	99.99%	100.00%

	January Portfolio Margin ($)		
	Basis - Fees & Congestion	Basis - Congestion	Hedge MtM
1/2/2023	($264,642)	($256,372)	$179,308
1/3/2023	($230,527)	($208,589)	$42,059
1/4/2023	($257,053)	($247,936)	$110,837
1/5/2023	($325,815)	($321,702)	$190,762
1/6/2023	($419,648)	($397,178)	$282,285
1/9/2023	($171,476)	($161,271)	$220,610
1/10/2023	($268,566)	($264,309)	$188,900
1/11/2023	($161,270)	($176,482)	$87,782
1/12/2023	($381,728)	($373,907)	$269,845
1/13/2023	($427,662)	($422,371)	$320,323
1/17/2023	($108,604)	($139,671)	$179,393
1/18/2023	$1,153	($47,807)	$212,731
1/19/2023	($295,735)	($328,679)	$326,502
1/20/2023	($312,720)	($302,417)	$246,283
1/23/2023	($234,194)	($268,681)	$117,962
1/24/2023	($184,319)	($189,528)	($75,805)
1/25/2023	($355,697)	($352,315)	$268,158
1/26/2023	($351,940)	($369,018)	$234,406
1/27/2023	($426,395)	($419,369)	$255,924
1/30/2023	($380,401)	($381,541)	$219,584
1/31/2023	($402,464)	($406,489)	$279,867
Total	($5,959,707)	($6,035,629)	$4,157,717
Hedge Effectiveness			
	70%	69%	

The hedge amount has been computed using PC analysis on congestion; so the hedge effectiveness computed using, only congestion component as a reference, is ~ 69% which is also the variation explained by PC1. The Hedge effectiveness computed using both congestion and fees is close about 70% which is along expected lines because Loss is a small component of Basis.

The PCA analysis for February as follows. As shown in table below, PC1 explains ~ 51% of P&L variation while PC1 and PC2 combined together explains 68% of variation in P&L. The Hedge effectiveness for February using only congestion as a reference is 57% which is close to variation explained by PC1. Similar to January, for February also, the hedge effectiveness using both congestion and losses is close to the former one.

In this example, only PC1 was hedged but PC2 can also be hedged. If that were to be done, a completely different instrument will have to be used because PC1 and PC 2 are orthogonal.

PCA Analysis for February	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
WEST	0.3051	0.4114	-0.4087	0.0376	-0.4009	0.3110	0.1384	0.5170	0.1591
PEPCO	0.4029	-0.1463	0.2088	0.3137	0.3717	-0.3024	-0.3590	0.5279	0.1925
DPL	0.2582	-0.4131	0.5288	-0.0740	-0.1723	0.2087	0.6125	0.1537	0.0741
PENELEC	-0.3718	-0.2194	0.2773	-0.3448	-0.4168	0.1925	-0.5459	0.3176	0.0906
DAYTON	-0.4572	0.0558	-0.0755	-0.0614	0.1422	-0.2376	0.2881	0.1063	0.7794
NI.HUB	-0.4587	0.0135	-0.0660	-0.0087	0.1782	-0.1985	0.3041	0.5564	-0.5584
ATSI	-0.0532	0.5463	0.5159	0.2636	-0.4185	-0.4224	0.0293	-0.0769	-0.0523
DUQ	-0.3215	0.1320	0.2162	0.6137	0.2162	0.6362	-0.0480	-0.0048	0.0441
COMED	0.1186	0.5209	0.3316	-0.5708	0.4731	0.2285	-0.0117	0.0518	-0.0001
Std Deviation	2.1409	1.2326	1.1844	0.9295	0.5810	0.4790	0.2182	0.1103	0.0611
Variance	4.5833	1.5194	1.4029	0.8639	0.3376	0.2294	0.0476	0.0122	0.0037
Cum Variance	4.5833	6.1027	7.5056	8.3695	8.7071	8.9365	8.9841	8.9963	9.0000
Ind. Var. Expln.	50.93%	16.88%	15.59%	9.60%	3.75%	2.55%	0.53%	0.14%	0.04%
Cum Var. Expln	50.93%	67.81%	83.40%	92.99%	96.75%	99.29%	99.82%	99.96%	100.00%

	February Portfolio Margin ($)		
	Basis - Fees & Congestion	Basis - Congestion	Hedge MtM
2/1/2023	($440,442)	($432,471)	$267,639
2/2/2023	($423,286)	($406,680)	$243,652
2/3/2023	($429,355)	($408,214)	$266,690
2/6/2023	($446,630)	($425,871)	$254,096
2/7/2023	($396,440)	($377,567)	$247,127
2/8/2023	($237,407)	($228,317)	$181,552
2/9/2023	($343,769)	($337,029)	$188,185
2/10/2023	($373,587)	($383,530)	$206,496
2/13/2023	($181,665)	($236,875)	$79,350
2/14/2023	($198,137)	($251,712)	$45,664
2/15/2023	($283,792)	($284,796)	($28,394)
2/16/2023	($432,281)	($431,711)	$212,537
2/17/2023	($302,032)	($306,281)	$199,559
2/20/2023	($275,284)	($262,407)	$146,193
2/21/2023	($370,250)	($349,011)	$243,323
2/22/2023	($357,364)	($335,818)	$253,857
2/23/2023	($374,576)	($353,784)	$239,541
2/24/2023	($434,273)	($417,025)	$258,450
2/27/2023	($407,500)	($397,848)	$234,569
2/28/2023	($298,871)	($298,779)	$223,659
Total	($7,006,939)	($6,925,724)	$3,963,746
Hedge Effectiveness			
	56.6%	57.2%	

7. Conclusion

The framework of Principal Component Analysis was employed to reduce the dimension of Basis portfolio and it was successfully used to hedge the Risk in the Basis portfolio for Winter 2023 delivery in PJM market. This methodology overcomes the limitations that portfolio managers faces to hedge the Basis Risks and it can employed to reduce variability in power portfolio.

References

1. H. N. E. BystrÖm, The hedging performance of electricity futures on the Nordic power exchange, Applied Economics, 2003
2. G.Zanotti & G.Gabbi & M.Geranio, Hedging with futures: Efficacy of GARCH correlation models to European electricity markets, Journal of International Financial Markets , Instituitions and Money, April 2010
3. J.Hanly & L.Morales & D.Cassells, The efficacy of financial futures as a hedging tool in electricity markets, International Journal of Finance and Economics, 2018
4. N. Kambhatla & T. Leen, Dimension Reduction by Local Principal Component Analysis, MIT Press Direct. July 1997.