Portfolio Optimization Applied for Wholesale Electricity Spot Market (Wesm) Based on Markowitz Theory

Mohammadreza Ghorbaniparvar, Fatemeh Ghorbaniparvar

Abstract— With the introduction of deregulation, the electricity market has turned from a monopoly market to a free market, while electric power distributor companies are facing a problem of designing the optimal portfolio in a competitive electricity market. Notionally, the portfolio selection problem can be solved by assigning requirement capacities to the spot market and bilateral contracts. This paper objective is to introduce a novel approach in order to address the electric power distributor companies' portfolio selection problem. Since electricity pricing is volatile and there is no ways to store electricity, this portfolio varies from a financial portfolio. The mathematical formulations and forecasted price of different asset returns for both the long term and the spot market portfolio selection have been derived according to Markowitz Modern Portfolio Theory. Moreover, we applied the data which comes from Manila Electric Railroad And Light Company (MERALCO) for different assets in this paper. Multiple Linear Regression Considering Explanatory Variables is employed to forecast the price of the spot market which is Wholesale Electricity Spot Market (WESM) in this paper. The portfolio selection problem for MERALCO is finally formulated as optimization problem, which can be solved by Genetic Algorithm (GA) in MATLAB and Microsoft Office Excel.

Index Terms— Portfolio Selection, Spot Electricity Market, Forward Contract, Futures Contract, GA.

I. INTRODUCTION

In earlier times, power generation and transmission sectors were controlled by national government. The generator's schedule was very authoritative since it was only concerned in trying to meet the demand requirements of a country while considering the thermal limitation of the network. In other words, there were no competitive markets in order to sell the power of the generators; as a result the electricity price was fixed. Finally, this structure privatized, which allowed establishing the Spot Market. In addition, there are a lot of different kinds of future contracts which guarantee the return, however it is not high revenue. Moreover, the utility companies have greater risks than before because of the significant price volatility in the spot energy market introduced by the deregulation. To hedge the risks, utility companies can select a number of financial instruments available in the electricity market, such as forward and futures contracts [1]. These issues could be considered as a portfolio selection problem.

The scheduling decisions of electric power distributor companies are critical in determining their profitability. Estimating market risk and management of such risks are crucial for electric power distributor companies in a competitive market. Risk indicates to the possibility of suffering harm or loss; danger or hazard. Risk management is the process of achieving a desired return/profit, taking into considerations of risks, through a particular strategy. Forward contracts are agreements to buy an arranged amount of the product at a decided price at an arranged time. Basically, the portfolio selection problem consist two sub-problems which are designing bidding strategy and minimize the risk by risk management. These problems have been extensively studied in literature [2]-[3]. Bilateral contract provides a high-income stability for the electricity supplier and high demand stability for the market consumers for a long time frame. Bilateral contracts in the electricity market are studied in literature [4]-[5]. Various aspects of risk management have been applied to the electricity market [6]-[8]. Diverse issues related to allocating the power requirement between the spot market and financial contracts also have attracted significant attentions [9]-[10]. A portfolio selection approach is proposed for utility companies to allocating its power requirement between forward contracts and the spot market based on Markowitz portfolio selection model [11]-[13]. The mean and variance of different asset returns are tabulated in utility function. Moreover, Genetic Algorithm (GA) that mimics the process of natural evolution is employed to optimize the fitness function. The reason for adopting GA is that GA can search for a global optimal solution and can simultaneously satisfy multi objective functions [14]-[15]. In addition, Multiple Linear Regression Considering Explanatory Variables is employed to forecast the spot market electricity price which could affect significantly on portfolio selection [16].

This paper presents a new approach for portfolio optimization in electricity market based on Markowitz Modern Theory using Genetic Algorithm. Furthermore, it is critical to mention, all simulations are performed in MATLAB and Microsoft Office Excel to present and deliver all the proposed concepts in appropriate way. Case studies are conducted with Philippines market data to prove that the proposed method is effective.

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II. METHODOLOGY

In order to address the portfolio optimization problem we need to fallow this process.

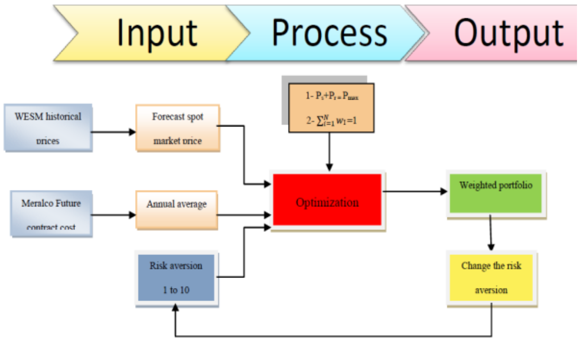

Fig 1. Portfolio optimization flowchart

A. WESM Historical Price

It is important to properly model the spot market price so as to derive the distribution parameters of different assets. The electricity price in the spot market is highly volatile and difficult to forecast. It is difficult to obtain accurate forecasts and not many advanced forecasting techniques are currently available for this problem. Therefore, we cannot directly calculate the mean and variance of the return of the spot market. In this paper we will use historical WESM price in order to forecast the spot market price. Regarding this, Multiple Linear Regression considering Explanatory Variables [16], which is more appropriate for WESM employed to forecast the spot price. Since the scope of this paper is not the forecasting, we are not discussing further about the forecasting.

Multiple Linear Regression Considering Explanatory Variables is a statistical technique that uses several explanatory variables to predict the outcome of a response variable. The goal of Multiple Linear Regression (MLR) is to model the relationship between the explanatory and response variables. Forecasting the spot price several months ahead is a long term forecasting problem. The full regression model was formed initially by choosing all possible dependent variables to serve as input in the regression model. Moreover, it was comprised of market price as the dependant variable, while the demand, aggregate supply, supply per fuel type, dispatch per fuel type, no offer generation, and price taker quantities are independent variable. The following equation illustrates the full regression model: [16]

$$\text{Spot price}_p = [\mu_0 \,.\, \text{supply}] + \sum_{i=1}^{j}[\,\mu i \,.\, \text{supply} - \text{fueltypei}] + [\delta_0 \,.\, \text{offer}] + \sum_{k=1}^{j}[\,\mu k \,.\, \text{offer} - \text{fueltypek}] + [\,\alpha_1 \,.\, p_{min}] + [\,\alpha_2 \,.\, \text{no} - \text{offer}] + \sum_{n=1}^{0}[\,\theta n \,.\, \text{dispatch} - \text{fueltypen}] + [\,\alpha_3 \,.\, \text{demand}] + \sum_{m=1}^{12}[\sigma m] + \sum_{d=1}^{7}[\eta d] + \sum_{h=1}^{24}[\rho h] + \varepsilon_p \quad (1)$$

Where:

$\alpha 1$ _ coefficient of the p min
α_2 _ coefficient of the no offer variable
α_3 _ coefficient of the demand variable
μ_0 _ coefficient of the total supply
μ_i _ coefficient of the supply per fuel type i
δ_0 _ coefficient of the total offer
δ_k _ coefficient of the offer per fuel type
θ_n _ coefficient of the dispatch per fuel type n
σ_m _coefficient of the month "m"
η_d _ coefficient of the day "d"
ρ_h _ coefficient of the hour "h"

B. Risk Aversion

The risk aversion degree represents the electric power distributor companies' attitude towards risk, which has considerable impact in portfolio selection. A is the risk aversion degree of the investor, which is the Meralco in our case. In addition, the utility of a portfolio is enhanced by high expected returns and diminished by high risk. Moreover, the risk aversion degree also has vital impact on the risk return trade off. This parameter is determined by the investor itself, however we will determine different portfolio for different risk aversion. The relationship between the risk aversion degree and optimal proportions of assets will be plotted in the next section. A= 1 to 10

C. Markowitz Modern Portfolio Theory(MMPT)

When Harry Markowitz was an economics student in University Of Chicago, he did a study on the stock market, in which he developed a theory that became a foundation of financial economics and revolutionized investment practice in making investment decisions, adherents of modern portfolio theory focus on potential return in relation to potential risk. The strategy is to evaluate and select individual securities as part of an overall portfolio rather than solely for their own strengths or weaknesses as an investment.

Expected portfolio return is the expected return of an investor based on his investment securities proportion and its expected return.

$$E[r_p]=\sum_{i=1}^{N} x_I \, E[r_i] \quad (2)$$

D. Optimization

In summary, given a set of assets, portfolio selection aims at selecting appropriate weights to optimize objective. This problem can be solved with a number of optimization techniques, such as Genetic Algorithm.

In portfolio selection, the return of an asset is usually modelled as a random variable. The mean of the random variable is then considered as the expected return of the asset, while the variance represents the risk. Assume that there are m assets available. Denote the return of asset i as r_i , and the mean and variance of r_i as μ_i and σ_i^2 respectively.

Then the return of the portfolio with m assets can be expressed as the weighted sum of the *m* variables [11]:

$$r = \sum_{i=1}^{N} w_i \, r_i \quad (3)$$

The mean and variance of the portfolio can be simply specified as [11]:

$$\mu = \sum_{i=1}^{N} w_i \, \mu_I \quad (4)$$

$$\sigma_P^2=\sum_{i=1}^{N}\sum_{j=1}^{N} wi\, w_j \operatorname{cov}(r_i, r_j) = \sum_{i=1}^{N} w_I^2 \sigma_i^2 + \sum_{i=1}^{N}\sum_{j=1}^{N} wi\, w_j \operatorname{cov}(r_i, r_j) \quad (5)$$

Since a higher return usually leads to a greater risk, a utility function is usually employed as the optimization objective to achieve a proper trade off [11]:

$$U = \mu - 0.05\, A\, \sigma^2 \quad (6)$$

Moreover, the risk aversion degree also has vital impact on the risk return tradeoff. This parameter is determined by the investor itself.

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Assume that the cost function of a generator follows a quadratic function of its dispatched generation capacity:

$$C(g)=(a+b.g+c.g^2)\, t\, \lambda^f \quad (7)$$

Where **g** denotes the dispatched capacity in the trading interval. And, $\boldsymbol{\lambda^f}$ represents the fuel price where t is the trading time of each trading interval. The parameters **a, b, c** are the private information of the generator. Note an important fact that, all the power of a generator is actually dispatched through the spot market. Therefore, denote g_s, g_f as the power sold through the forward contract and spot market respectively.

Let p_f, p_s denote the forward strike price and spot price, the return of the forward contract can be calculated as:

$$r_f = \frac{pf*gf-c(gf)}{c(gf)} \quad (8)$$

Where p_s denotes the spot electricity price.

Mean and variance of the future contract can be calculated as:

$$\mu(r_f)=\frac{pf*gf-c(gf)}{c(gf)} \quad (9)$$

$$\sigma^2(r_f) = 0 \quad (10)$$

For r_s, since the only random variable in r_s is p_s, the mean and variance of r_s can be given as:

$$\mu(r_s)=\frac{gs}{c(gs)}\,\mu(p_s)-1 \quad (11)$$

$$\sigma^2(r_s)=\left[\frac{gs}{c(gs)}\right]^2 \sigma^2(p_s) \quad (12)$$

In this paper, Multiple Linear Regression Considering Explanatory Variables [16] will be used to forecast the spot price. The variance of p_s can be obtained by simply calculating the variance of p_s in the corresponding period in last year.

Furthermore, the sum of weighted power for each future contract and spot market should be equal to output of the generators.

$$P_s+P_r = P_{max} \quad (13)$$

$$\sum_{i=1}^{N} w_I = 1 \quad (14)$$

E. Genetic Algorithm

Genetic algorithm (GA) is a method for solving both constrained and unconstrained optimization problems based on a natural selection process that mimics biological evolution. The algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm randomly selects individuals from the current population and uses them as parents to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution.

Following flowchart shows GA's procedure to find the best solution:

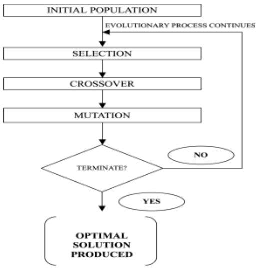

Fig 2. Genetic Algorithm flowchart

III. Result And Discussion

The primary concern of every power consumer is to lower his or her electricity bill without increasing risk. The volatility characteristics of the spot prices provide a risky opportunity for consumers to achieve their objective in shrinking their bills. In this section, the effectiveness of the proposed approach is demonstrated with data in the Philippines market. The Wholesale Electricity Spot Market (WESM) is selected for case studies in this paper. The price model of the spot market is built based on the market data from 2012, which is published in the official website of WESM [19]. A case study model has been constructed based on Markowitz portfolio theory using Microsoft Office Excel and Genetic Algorithm in Matlab. Multiple Linear Regression Considering Explanatory Variables is employed to forecast the price of spot market. The information of the experiment is given in table 1.

Table 1. Case study Information

Private Information		Public Information	
Cost Function Parameters	a=4428 b=233.7 c=0.02	**Historical data of the spot market**	WESM from,2012
Risk Aversion	1 to 10	**Forward Contract Price (NPC) PHP/MWh**	5372.355

- We will prove that our method is able to achieve a proper trade off between return and risk by comparing the Mean and standard deviation of the proposed portfolio with other portfolios.
- The impacts of Risk aversion by altering it on portfolio selection will be investigated.
- Compare the results with the Meralco Portfolio in constrained situation.

Assume that in Oct 2012, the generation company is designing its portfolio for Nov 2012. It firstly employs Multiple Linear Regression Considering Explanatory Variables to estimate the mean spot price in Nov, and solve the optimization problem by Genetic Algorithm in Matlab. The portfolio obtained with the proposed method is given as: (A=5)

Table 2. Mean and SD of the proposed portfolio

Proposed Portfolio	A=5	Mean (PHP/KWh)	SD of Return
WESM	82%	13.52365	5.0669
NPC	18%	0.190734	0

The illustration shows the Mean of return and standard deviation of our securities. While in the proposed portfolio WESM has a great revenue, standard deviation is a large number. By setting the best weight according to risk aversion we found best trade off portfolio.

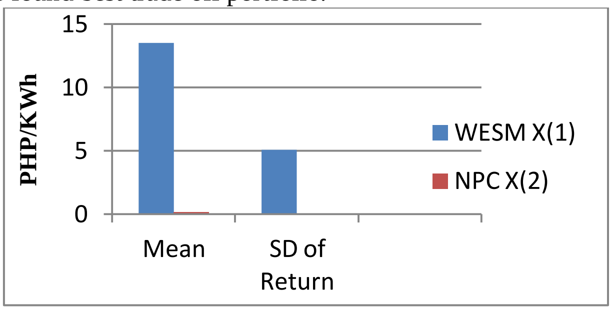

Fig 3. Mean and SD of Proposed Portfolio

To validate that the proposed portfolio is superior to alternative strategies, we calculate its actual revenue with the real market data of Nov 2012, then compare it with the performances of other two strategies, which are allocating all capacity to the spot market and allocating all capacity to the forward contract.

Table 3. Mean and SD of NPC, WESM and Proposed Portfolio

Asset	Mean of the return (PHP/KWh)	SD of the return
Allocating all requirement in future contract(NPC)	0.151929	0
Allocating all requirements in Spot market (WESM	18.24054	18.5275
Proposed Portfolio	13.52365	5.066979

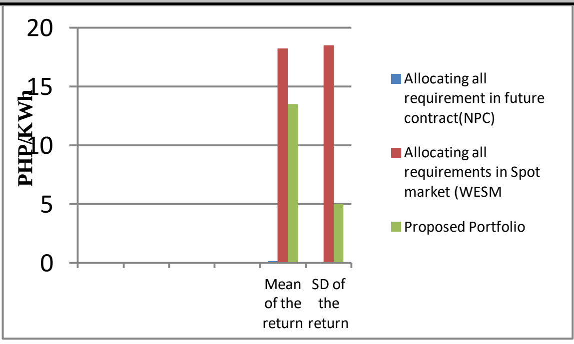

Fig 4. Mean and SD of NPC, WESM and Proposed Portfolio

In Table 3, the actual revenue is calculated by assuming that the corresponding portfolio is applied, while spot market prices are set as the real market prices in Nov 2012. As shown in Table 3, if the proposed portfolio is employed in Nov 2012, its revenue will be close to the actual revenue of allocating all capacity to the spot market. However, the standard deviation of its revenue is much smaller, indicating that it has much lower risks than selling all power in the spot market. Moreover, the difference between the actual revenue and expected revenue of the proposed portfolio is insignificant. This implies that the proposed method can appropriately estimate the return characteristics of different assets.

The risk aversion degree represents the power distributer Companies' attitude towards risk, which has significant impact in portfolio selection. The relationship between the risk aversion degree and optimal proportions of assets is plotted in Figure 5. As observed, the forward contract will have less proportion in the proposed portfolio if the risk aversion degree rises. This phenomenon is reasonable since allocating greater power requirement to the forward contract can decrease risks.

Table 4. Proposed Portfolio for risk aversion 1 to 10

A	1	2	3	4	5	6	7	8	9	10
WESM(%)	5	55	71	78	82	86	88	89	90	92
NPC(%)	95	45	29	22	18	14	12	11	10	9

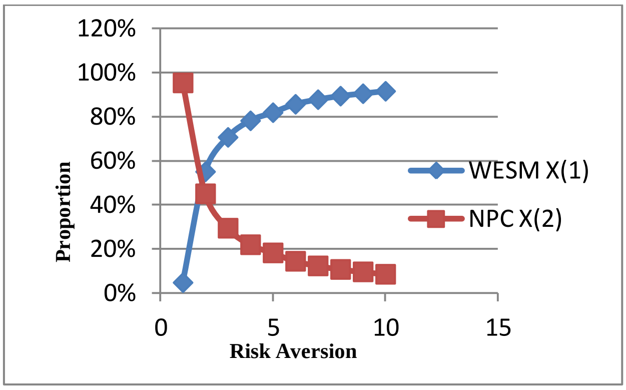

Fig 5. Proposed Portfolio for risk aversion 1 to 10

The standard deviation of the spot market is an important factor in portfolio selection and it has a significant impact on our portfolio. The information of this experiment for increased Standard deviation, and decreased standard deviation is stated in table 5.

Table 5. Proposed portfolio for increased SD, and decreased SD

A	1	2	3	4	5	6	7	8	9	10
WESM(%)	5	55	71	78	82	86	88	89	90	92
NPC%	95	45	29	22	18	14	12	11	10	9
WESM(%) (decreased STD)	53	76	85	86	91	93	94	94	95	96
NPC(%) (decreased STD)	47	25	15	14	9	8	6	6	5	4
WESM(%) (increased STD)	0	0	0	17	36	47	55	61	65	69
NPC(%) (increased STD)	100	100	100	83	64	53	45	39	35	31

As we can see, the standard deviation plays an important role in portfolio selection. In this experiment we used the standard deviation of WESM for 2 last years from 2009 to 2011. This experiment shows that the small standard deviation would increase the proportion of the spot market in portfolio selection, while the great standard deviation would decrease the spot market proportion. Figure 6 plotted the proportion of WESM and NPC for regular standard deviation, increased standard deviation, and decreased standard deviation.

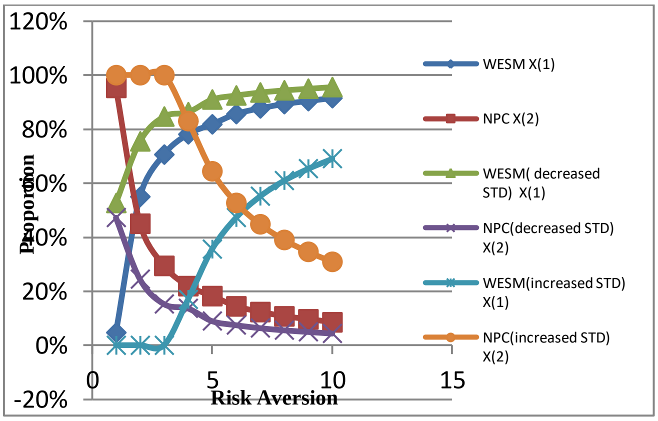

Fig 6. Optimal Proportion for Regular STD, Increased STD, and Decreased STD

Moreover, proposed method applied to two case studies and the results are plotted.

The characteristics of case 1 are

- NPC price: 2000 pesos
- WESM price: 15000 pesos
- A= 1 to 10
- Variance: historical data

Table 6. Proposed Portfolio for Case Study 1

A	1	2	3	4	5	6	7	8	9	10
WESM(%)	0	0	1	24	40	50	57	63	67	70
NPC(%)	100	100	99	76	60	50	43	38	33	30

As the table 6 shows, when future contract price is very smaller than spot market price, utility companies are interested to get their power requirement from future contracts if they are not willing to take a high risk. On the other hand, the proportion of the spot market to feed the utility companies is high when they are very risky and they are looking for great revenue. The proportion of the spot market and the future contract plotted in figure 7 for risk aversion 1 to 10.

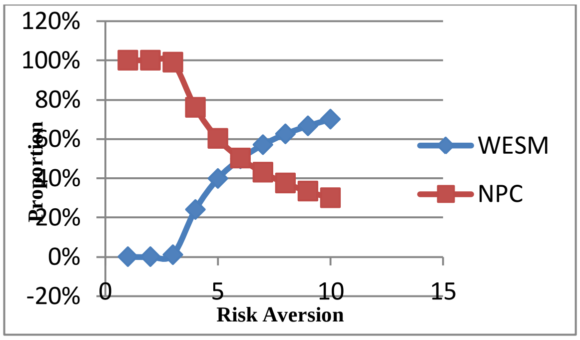

Fig 7. Proportion of the Spot Market and the Future Contract for Case Study 1

The characteristics of case 2 are

- NPC price: 2000 pesos
- WESM price: 2000 pesos
- A= 1 to 10
- Variance: historical data

Table 7. Proposed Portfolio for Case Study 2

A	1	2	3	4	5	6	7	8	9	10
WESM(%)	62	81	88	91	93	94	94	95	96	96
NPC(%)	38	19	12	9	7	6	6	5	4	4

In case study 2, the price for the spot market and future contracts are the same, while variance of the spot market plays significant role. In other words, this method suggests that when there is a same price in the spot market and future contract purchasing power requirement from the spot market would be very beneficial even though power distributor companies are not willing to take a risk. Information of this case study plotted in figure 8.

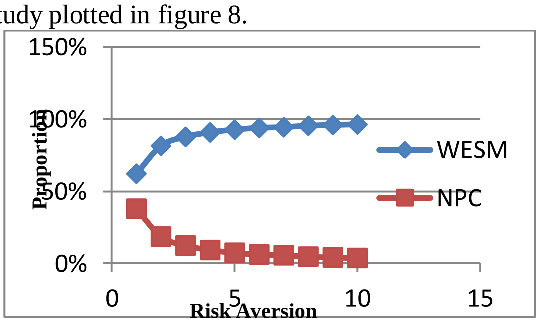

Fig 8. Proportion of the Spot Market and the Future Contract for Case Study 2

In order to propose a portfolio for Meralco we need Meralco's generator capacities and the price of each generator. Meralco has received its power requirements from the spot market and 8 Generators which are First Gas Power Corporation Santa Rita(Sta. Rita), First Gas Power Corporation San Lorenzo(San Lorenzo), Montalban Methane Power Corporation(MMPC), Bacavalley Energy Inc(Bacavalley), Pilipodeco, Quezon Power Philippines(Limited) Company(QPPL),Sem-calca Power Corporation. Table 8 states their capacity and annual average price.

Table 8.Generators' Capacity and Annual Average Price of Generators' Companies

Name of the generator	Capacity (MW)	Price(PHP/MWh)
1. SEM Calaca - Coal Power Plant	600	3999.98
2.QPPL – – Coal Power Plant	511	5402.563636
3. Sta. Rita –Natural Gas Combined Cycle Power Plant	1047	5344.709091
4. San Lorenzo – – Natural Gas Combined Cycle Power Plant	549.1	5307.227273
5. Philpodeco —Hydro Plant	1.116	5686.554545
6. MMPC – Biomass Power Plant	8.19	4164.527273
7.Bacavalley–Biomas	4.212	4115.927273
8.National power corporation	1700	5372.355

Although there are a lot of limitations such as Energy Regulatory Commission (ERC) rules, type of generators, and Generator's capacity for Meralco to select its portfolio, we propose a portfolio for Meralco which is near to Meralco's original portfolio. Table 9 shows the information regarding Meralco's portfolio which is published on their official website and proposed portfolio for Meralco based on proposed method and considering the generators' capacity.

Table 9.Meralco's Portfolio and Proposed Portfolio for Meralco

	Meralco's Portfolio (%)	Proposed Portfolio For Meralco(%)
NPC	27.70	29.50
WESM	12.90	13.00
SEM-Calca	4.30	11.60
QPPL	7.40	14.18
San Rita	23.30	19.59
San Lorenzo	11.70	12.05
Philpodeco	0.01	0.04
MMPC	0.10	0.03
Bacavalley	0.02	0.02

Figure 9 illustrates and compares the results which come from proposed method and Melaco's original portfolio.

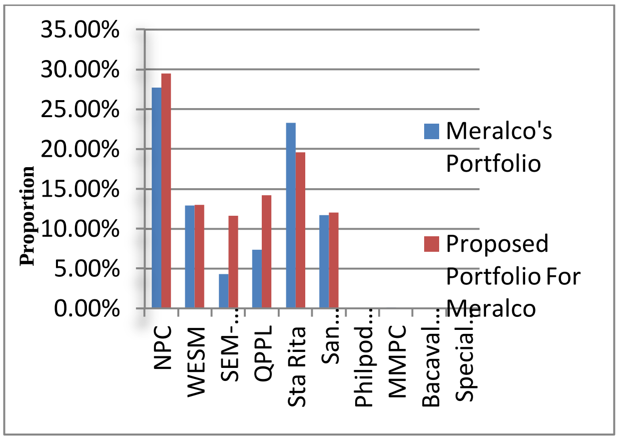

Fig 9. Proposed Portfolio and Melaco's Original Portfolio

IV. CONCLUSION AND RECOMMENDATION

Creating a complete portfolio optimization in the electricity market is a wide scope project that requires some financial background knowledge integrated with the electricity market knowledge. The special characteristic of electricity makes it even harder to create a portfolio of it. In this study model created, its main focus is on purchasing electricity to spot market and future contract. In deregulated electricity markets, electricity companies have a difficult task of buying the optimal portfolio to achieve their power requirement, which consists of a variety of spot markets and future contracts with different characteristics. Basically, the portfolio selection problem aims at allocating electricity companies' power requirement to proper markets and future contracts, so as to achieve the optimal trade off between return and risk. In this paper, a novel approach is proposed to solve the electricity companies' portfolio selection problem. Eventually, the portfolio selection problem is tabulated as an optimization problem, which can be solved by the Genetic Algorithm in MATLAB. The proposed method is tested with the Philippines electricity market and all the inputs come from Meralco's official website and WESM's official website. Its effectiveness is demonstrated by changing all inputs and comparing it with actual results in case study 1 and 2. Moreover, it is composed of two features linked to produce a new method that is beneficial for utility companies but it is limited in some aspects. Future work should look further into the demand of the customers and apply different forecasting methods which could be matched with characteristics of the spot market in order to forecast the spot market price. The weather condition is playing a significant role which could affect directly on consumers' demands and consequently on the spot market price. That is why changing the forecasting method and comparing the new results would be interesting. This is used as prevention in case of any unexpected increase in demand. As technology advances there would be multiple bilateral contracts with different characteristics in the electricity market in the future and there would be more than one spot market. Implementing a method with diverse future contract and with two to three spot markets could be assumed as future work. Genetic Algorithm is employed to optimize the utility function while there are a lot of optimization methods. Employing other kinds of optimizers also could be critical and there would be great consequences.

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