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THE CHALLENGE OF A REAL, COMPLEX HYBRID PROJECT

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Abstract

This paper explores the implementation process of a hybrid power plant project (HyPP) in the Philippines' deregulated and complex energy market. SN Aboitiz Power (SNAP) owns and operates the Magat HyPP which involves integrating a 388 MW hydropower plant with a 24 MW/32 MWh battery system and a 280 kW pilot floating solar (FPV), planned for expansion. Scatec ASA, OceanSun and Prediktor, with support from the research partners IFE and SINTEF Energy Research, are contributing to the development of Magat HyPP under the HydroSun innovation program with financial support from Innovation Norway and the Research Council of Norway.

No regulatory framework exists in the Philippines for implementing FPV or HyPPs. During the development of Magat HyPP, it was uncovered that 50 permits and agreements were required to implement the project. Ocean Sun, the FPV system supplier used methodologies for design and verification from offshore aquaculture and has thus ensured insurable guaranties for the installations. Prediktor has developed an Energy Management System for real-time hybrid optimization. The value creation potential from Magat HyPP is assessed with the Short-term Hydro Optimization Program (SHOP) developed by SINTEF. The results indicate that the annual revenue can increase by 4 % under a hybrid power purchase agreement (PPA) compared to standalone production.

1 Introduction

Variable renewable energy (VRE) makes up an increasing portion of the global electricity mix. Finding profitable solutions for handling intermittency is essential for solving the energy trilemma; affordable, reliable and sustainable energy supply to everyone. The challenge becomes increasingly urgent challenge: VRE is growing rapidly and already make up a large share of all produced electricity in several markets. Hybrid power plants (HyPPs) are anticipated to become increasingly important in this context. Such power plants typically incorporate two or more complementary technologies for electricity generation, including energy storage. HyPPs are typically defined by a single grid connection point.

By incorporating complementary sources of renewable electricity production and energy storage, HyPPs can deliver electricity reliably across multiple time scales. Resource complementarity and storage enable HyPPs to better adapt production to demand through e.g., peak shaving and to perform energy arbitrage. HyPPs can also be designed to support power quality by offering e.g., contingency reserves, regulation reserves, frequency response and black start. This can enable HyPPs to participate in different energy markets with different requirements: energy only-markets, capacity markets and markets for ancillary services. Research from our project also indicates that HyPPs can be designed to be more robust towards fluctuations in available resources (inflow, irradiance, wind), and as a consequence also potentially more resilient to climate change than power plants based on one renewable generation technology. Hence, the ultimate HyPP design and profitability will depend on both the locally available energy resources, selected technologies and local market and relevant regulatory frameworks which among others regulate which markets (energy, capacity, ancillary) a HyPP has access to.

1.1 Hybrid Power Purchase Agreements

The top consideration for power producers when assessing HyPPs and storage capacities is according to Pexapark [1] to maximize the assets flexibility for future revenue streams, followed by CAPEX cost. Estimating and proving the **value creation** of a hybrid asset is a core challenges in order to accelerate investment decisions. The value to society is especially related to the need for transmission line upgrading costs and the socioeconomic value of reliable and affordable energy production. The cost-benefit to the power producer can

only include the expected **value capturing** by the revenue streams in the future market in addition to risk reduction.

The energy markets around the world are under development. Pexapark [1] has summarized the status of how project owners can capture the value of hybrid assets. Securing hybrid power purchase agreements (PPA) allowing for a contractual agreement leveraging benefits both for the grid- and asset-level is essential. The idea is to generate revenues through grid services, while improving the investment returns of the renewable asset.

1.2 General benefits of Floating PV

Floating PV (FPV) has several benefits beyond mere power generation; land is increasingly scarce and costly, and FPV contributes to freeing up land for other purposes such as food production or conservation. Ocean Sun's patented membrane-based technology for FPV allows for thermal contact between the water body and the modules, lowering the solar cell temperature and thus increasing the power output by 8-10% [2]. HyPPs combining hydropower and FPV can be used to save water for periods when there is more need for the water and higher prices. It adds value for the plant owner, and it gives the power consumers a more stable and predictable power supply and reduces emissions.

1.3 SNAP Magat HyPP and the Philippine energy market

SN Power Aboitiz (SNAP) in the Philippines is developing a HyPP that can utilize the existing 388 MW hydropower plant's complementary advantages with FPV and a battery energy storage system (BESS).

SNAP wants to include FPV because it allows for optimizing the existing dam infrastructure and reduces the need for new land conversion. Ocean Sun's modules allow for increased value creation through more efficient water-cooled solar modules and low CAPEX. FPV is a relatively new technology. The possibility to further validate performance and reliability and optimize the whole process from logistics to construction and condition-based maintenance is also important for the supplier, Ocean Sun.

Scatec and SNAP evaluate projects based on the attractiveness of the business case, including the tariff potential and expectations on profitability, how to secure off-take opportunities and contracts, financial solutions, and the likelihood of securing land access and grid access.

The deregulated and competitive energy market in the Philippines is attracting private investments. The relatively weak grid in the Philippines faces challenges in delivering stable and reliable electricity supply due to inadequate transmission lines, limited interconnections, voltage fluctuations, and capacity constraints. The market's increasing focus on ancillary services and environmental sustainability opens doors for HyPPs. But the current energy market requires that each power generation units have to be registered as separate market participants. A future regulatory framework (or TSO) should allow for HyPPs to bid in energy and ancillary services for combined assets.

1.4 Hypothesis about value capturing.

With Magat HyPP we want to prove the value creation of an optimized power production to the society and grid operator, but especially to the power producer (SNAP). With a through prove of **value creation**, and a suggestion of Hybrid PPA's to the authorities and grid operator, it should be possible to obtain **value capturing** at Magat HYPP if the regulatory framework is changed.

2 Methodology

In this paper, we do a systematic review of the development process of the Magat HyPP in the Philippines. SNAP and Scatec are the developers, TGS Prediktor develops the Energy Management System (EMS), and Ocean Sun is the technology provider of the floating solar modules. Sintef is modelling the Magat HyPP in their Short-term Hydro Optimization Program (SHOP) and IFE assist with basic scientific research on both floating solar and hybrid energy systems. We are focusing on the key constraints, the key factors for success and the main challenges to mitigate.

2.1 Hybrid Power Plant Development Ambitions

SNAP is the second largest renewable power producer at the Philippines, with an average annual generation of 1,476 GWh for the past 5 years and has high ambitions on further development of renewable energy in the country. Within expansion scope are wind, solar, hydropower and BESS. The ambitions on floating solar alone is 114 MW by 2028. The small 280 kW pilot FPV at Magat, has given faith in the membrane and mooring system provided by OceanSun. An expansion of Magat FPV up to 67 MW_p is assessed, but with a first stage of 10 MW_p is regarded to be most beneficial due to transmission line constraints.

At Magat, there is an existing 388 MW hydropower plant, with 4 Francis units of 97 MW each, and a maximum turbine discharge of 552 m^3/s. The live reservoir storage of Magat reservoir is 615 Mill m^3 and correspond to about 13 days of full production, or 130 GWh storage (without new inflow). Priority of the water use in Magat reservoir is to irrigation, and the irrigation diversion requirements are given on a weekly basis. The downstream SNAP Maris hydropower plant, on the downstream reregulation pond ensures stable release of irrigation water.

A 24 MW chemical battery with 32 MWh storage capacity was commissioned in 2023. Magat BESS is originally designed to serve the frequency reserve market, with a separate grid connection point and a contract favouring a 50 % State of Charge (SOC) to take both up- and down ramping equivalent to the battery's full power rating for a duration of 30 minutes. The frequency response market is still nascent in the Philippines. However, it was confirmed by the system operator that the requirements for frequency support are defined by a set of static and dynamic parameters including build-up time,

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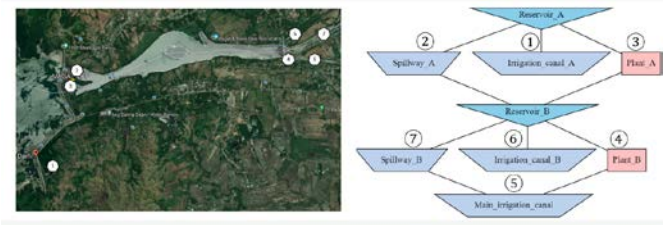
settling time, and steady-state regulation accuracy. The fast response times of battery systems, their precise and accurate control, and their relatively high energy density rendered a battery as the most appropriate solution for participation in the frequency response market from a site with some space constraints.

Experience from development of Magat HyPP is regarded as important to future development of hybrid powerplants for SNAP and Scatec.

2.2 Estimation of value creation

The Short-term Hybrid Optimization Program (SHOP) v15.3.3.2. is the scheduling tool used to estimate the added value creation of the integrated Magat HyPP compared to standalone assets. CPLEX 20.1.0 is the solver being used. The hybrid scheduling problem is modelled under an assumed future Hybrid PPA. The prices are given in Philippine Pesos (PHP). Conversion to USD is approximately 56:1.

Figure 1 illustrates the complex set-up of the Magat hydropower plant. The irrigation requirements for Canal A and Canal B have to be fulfilled. There is a minimum flow constraint for the downstream main irrigation canal. The default penalty for breaking those requirements is 100,000 PHP/m^3/s.



	Reservoir_A	Reservoir_B
Max water level (meter)	193	107.8
Min water level (meter)	160	101.5
Max volume (million m³)	632.8	14.9
Max surface area (km²)	28.5	2
	Plant_A	**Plant_B**
Outlet line (meter)	104.6	95.7
Generator max production (MW)	97 * 4	4.25 * 2
G1/G2 min production (MW)	2 * 4	0.5 * 2
G1/G2 Start cost (PHP)	300	12

Figure 1 The complex set-up of the Magat hydropower Plant.

The test is run on three situations of energy sources and storage (Table 1) with or without reserve obligations (Table 2), giving six scenarios to compare.

Table 1 Three combinations of energy sources and storage

	388 MW Hydro Power
	388 MW Hydro Power 10 MW_p FPV
	388 MW Hydro Power 10 MW_p FPV 24 MW/32MWh BESS

Table 2 Two combinations of market and reserve obligations

Markets	**Short description**
Day-ahead market	Energy
Day-ahead market + Contingency reserve (CR) + Dispatchable reserve (DR)	Energy + Spinning reserve (running turbines synchronized to the grid) + Reserved capacity from the black start

The main output values are calculated as follows:

$$Net\ revenue = Market\ income + CR\ reserve\ income + DR\ reserve\ income - Start\ cost - Min\ flow\ penalty\ cost \quad (1)$$

where

- $Market\ income = \sum_t sale\ amount_t \times market\ price_t$ $Market\ price_t$ comes from the day-ahead market.
- $CR\ reserve\ income = \sum_t 2{,}250 \times (CR\ obligation_t - CR\ violation_t)$
- $DR\ reserve\ income = \sum_t 850 \times (DR\ obligation_t - DR\ violation_t)$
- $Start\ cost$ is the sum of the start cost of all the generators during the scheduling period.
- $Min\ flow\ penalty\ cost$ is the sum of the penalty cost for breaking the flow constraints of the irrigation canals.

$$Total\ production = \sum_t (hydro\ production_t + FPV\ production_t + BESS\ discharge_t - BESS\ charge_t) \quad (2)$$

$$Average\ price = Net\ revenue / Total\ production \quad (3)$$

3 Results

Development of a real HyPP gives many challenges. Despite all these challenges, we are still pursuing the opportunity of SNAP Magat HyPP. A 10 MW floating solar is the largest installed capacity that can be captured by the existing grid.

3.1 Framework for hybrid power plants

Based on the lessons from the Magat Pilot Floating Solar and the ongoing process towards the authorities, the following are the important permits and agreements SNAP have to obtain for a 10 MW FPV installation.

Table 2 Major Permits and agreements to obtain for Magat HyPP, including floating solar.

Agency	**Permit**	**Potential timeline**
National Irrigation Administration	Water Lease Framework	12 to 18 months

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Department of Environment and Natural Resources	Environmental Compliance Certificate	10 – 12 months
Local Government Unit	Several Permits	1 – 3 months
Distribution Utility	Distribution Impact Study as applicable	2 – 4 months
Energy Regulatory Commission	Certificate of Compliance	6 – 12 months
National Grid Corporation	System Impact Study as applicable	10-12 months

A total of 50 permits has been identified. 30 of those are considered Primary permits that the owner or developer would need to secure while the rest are normally subcontracted to the EPC to facilitate.

Magat Floating Solar will be the first in the Philippines and there exist no agreed water lease fees. The National Irrigation Authorities has suggested a quite high percentage of all income from the FPV, which will give a far too low IRR, regarding the important investment cost. Negotiations are ongoing. Uncertainties on potential tariffs for a hybrid asset, makes the negotiations more complicated.

The most important issues for the local government and the local communities are related to fishing activities and transportation over the reservoir. Regarding fishing, it is important to plan for the floating solar panels not to interfere with the important locations for fish cage. Magat reservoir has also many transportation routes for small boats. The location of the floating solar rings should be located as close to the grid connection point as possible. The most used transportation routes today will be hampered by the planned location of floating solar, as their point of departure is at the dam entrance, next to the road. This location is also important for fish trading. Many of the boat transport drivers are waiting for their passengers, typically school students or people going to the nearest city for business.

In order to mitigate the inconveniences for fisher men and boat drivers, it is suggested to make a new quay structure, including access road, for both fishing boats and transport boats. The quay can be used during mounting of the floating solar ring. And the quay can also be equipped with freezer boxes for improving the fish trade. It is also possibilities to offer the boat drivers to have an additional income from cleaning the floating solar panels as they are waiting for passengers anyway.

There are also communities around Magat reservoir with indigenous people. Indigenous people have luckily a very good protection. If any areas with indigenous people are affect, a Free, Prior, and Informed Consent (FPIC) process is launched. A FPIC allows Indigenous Peoples to provide or withhold/withdraw consent, at any point, regarding projects impacting their territories. It is therefore decided to make sure no areas with indigenous people are affected by Magat HyPP.

3.2 Financial solutions and Hybrid PPA's

The regulatory framework for commercial scale floating solar assets in the Philippines is still in the early stages. So is the framework for hybrid operation of assets. The two processes are mutual important to SNAP, as the possible value capturing in the merchant energy market is high for both technologies and can be increased if the solar and water resources could be co-optimized to stabilize the intermittent PV generation.

The well-developed energy market in the Philippines has both day-ahead energy market, with a 5-minute intra-day trading option, and three different Ancillary Service (AS) markets. The Contingency Reserve (CR) market is the spinning reserve, the Dispatchable Reserve (DR), market is when you can have black start, and the Regulating Reserve (RR) for frequency regulation in the grid. Magat Hydropower plant participates in all three AS markets, while BESS can only participate in CR and RR. The contract prices for all the three ancillary service markets are constant for 5 years at the time. As of today, a market participant cannot bid in a HyPP either on the spot market nor the AS markets.

Today, at the existing Magat hydropower plant, about 77% of revenue comes from Energy Sales and 23% comes from Ancillary Services. The high-income potential from ancillary services, suggests that the value of selling PV under a hybrid Power Purchase agreement, where the storage capacity in the hydropower reservoir and the BESS can be utilized to limit the need for volume being sold on the balancing markets, should create value to both the society and to the asset owner.

As only contracts for stand-alone assets (not hybridized assets) are available by now, a process towards the authorities, Department of Energy, National Electrification Administration and National Grid Corporation of the Philippines must be convinced about the mutual benefit of hybrid PPAs and hybrid asset participation in both spot and AS markets. SNAP takes the offensive approach and is working with the regulatory bodies and provides suggestions and feedback on the process.

3.3 FPV - Typhoons and insurance

To reach financial close of a floating solar project, insurance guaranties are needed. Ocean Sun is providing a proprietary technology for FPV power plants, and design and dimension the FPV system at Magat dam. The Philippines is a typhoon prone country, and typhoons represent a potential risk to FPV installations. Insurance guarantees is therefore important to mitigate this risk for the buyer. The system is designed to withstand a wind speed of 275km/h (Typhoon class 4).

The pilot FPV system installed at Magat has been in continuous operation for 4 years and has not been affected by the yearly Typhoon seasons. However, typhoons do represent a potential risk to FPV installations. Ocean Sun is working

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closely with third party institutions such as Det Norske Veritas (DNV) and Bureau Veritas to verify various aspects of the technology, such as mooring, anchoring and the overall structural integrity of the system for a specific project location. DNV and Bureau Veritas are ensuring that the calculation methodology used by Ocean Sun is correct and that the design adheres to the relevant standards, thus reducing risks. Relevant standards include Ocean Suns Design Basis and Hydrodynamic Design Premise, the aquaculture design code NS 9415 and the floating solar recommended practice DNV-RP-0584. This makes it easier to insure the system against damage caused by weather conditions, and at a lower premium. Ocean Sun has obtained insurance for the system.

3.4 Automated digital tool

To capture the value from hybridization, we need to prove that we can automate the optimization and develop a reliable tool for the production planners and operators. TGS Prediktor is developing a real-time hybrid EMS optimization software tool. The purpose of the tool is to optimize the energy service revenues by automatically allocating assets to different energy market services. The data taken into consideration is among other minute resolution market prices, second resolution weather and inflow data, asset design limitations (i.e., BESS cycle limitations, HEPP ramp-up dynamics) and license requirements (water volume release for irrigation, reservoir rule curves, etc). This real-time multivariate optimization challenge is solved using Model based Predictive Control (MPC) and Quadratic Programming (QP) algorithms [7]. It is designed to become generic and usable for any hybrid real-time EMS optimization challenge, communicating with the various SCADA- and control systems in the hybrid plant.

The main components of the real-time hybrid EMS optimization tool are shown in the inside the dashed square in the diagram below:

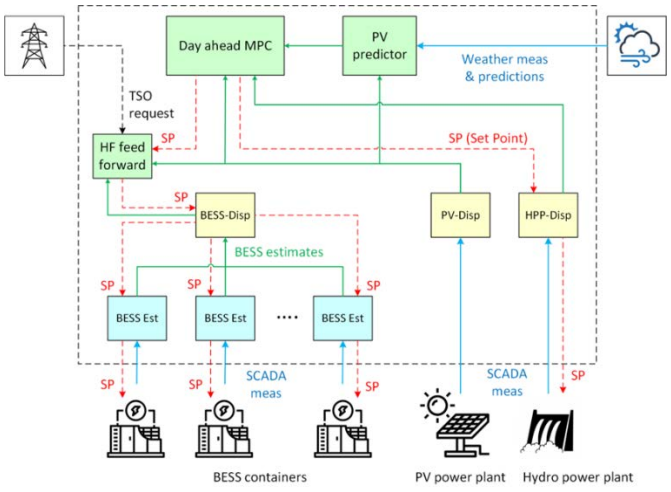

Figure 2 Overview of the real-time hybrid EMS optimization tool indicating the data flow.

As an example, assuming an agreement for delivering a fixed load through peak hours of a day, with some relevant weather conditions, a simulated scenario looks like this for the predictions and control commands this system would make (ref [3], [4], [5] & [6]):

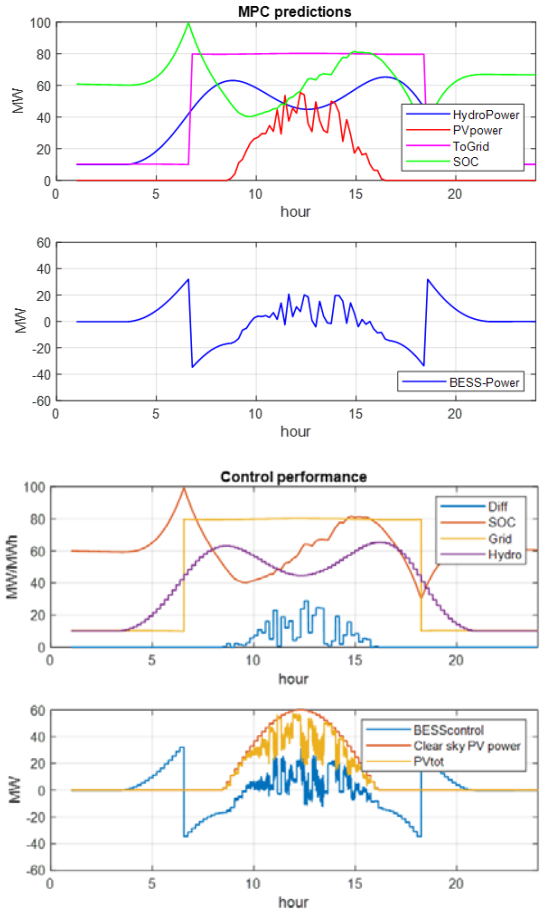

Figure 3 Snapshots from a simulation of the hybrid EMS optimization tool running the optimal predictions during a 24-hour horizon run. "MPC predictions" show the Model based Predictive Control predictions of the optimal power generation needed to deliver the specific power profile target to the grid and the BESS state of charge. In "Control performance", we see the control set-points the system will generate to the HEPP control system and BESS, given the simulated PV power profile, PVtot.

3.5 Value creation at Magat HyPP – SHOP results

The scheduling period is one year with hourly time resolution. Input data from 2021 is used as a reference year, as it was close to a median year in terms of inflow. The initial and end conditions in the optimization model are that both reservoirs start and end at the maximum water level. Evaporation from Magat Reservoir is considered, and FPV covers 1% of the reservoir's maximum surface area. It is assumed that the energy used for charging BESS cannot be bought from the market, only from own production (hydropower and solar).

Table 3 and Table 4 compare the results for the six scenarios defined in Section 2.2 without or with reserve obligations, respectively.

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Table 3 SHOP results for a Day-a-head market

Asset combination	**Net Annual Revenue [Bill. PHP]**	**Total Production [GWh]**	**Average price [PHP/MWh]**
Hydro only	7.61	940	8.095
Total stand-alone	7.70	956	8.054
Hydro		*940*	
FPV (curtailed)		*15.3 (-0.08)*	
Total hybrid	7.93 **[+3.0%]***	948 **[-0.7%]***	8.359 **[+3.8%]***
Hydro		*937*	
FPV (curtailed)		*15.4 (0)*	
BESS discharge		*44*	
BESS charge		*-49*	

*Note: *Compared with the values in the Hydro + FPV alone scenario.*

Table 4 SHOP results for a Day-a-head market + CR reserve and DR reserve.

Asset combination	**Net Revenue [Bill. PHP]**	**Total Production [GWh]**	**Average price [PHP/MWh]**
Hydro only	7.83	733	10.68
Total stand-alone	7.91	746	10.59
Hydro		*731*	
FPV (curtailed)		*15.3 (-0.10)*	
Total hybrid	8.23 **[+4.1%]***	743 **[-0.5%]***	11.07 **[+4.6%]***
Hydro		*734*	
FPV (curtailed)		*15.4 (0)*	
BESS discharge		*60*	
BESS charge		*-66*	

*Note: *Compared with the values in the Hydro + FPV alone scenario.*

In a merchant market, as the current Philippine market, the hydropower plant, with reservoir storage, will always be optimized towards the market prices. Energy from FPV plant can always be sold at the same price as you can buy the same energy from the market. The value of hybrid operation and optimization of hydropower and PV in this merchant market is therefore not existing, and the value is equal to stand-alone assets. But when battery energy storage systems (BESS) are included in the mix, it is possible to capture more value, both for the hydropower plant and for the solar plant. The actual value of standalone BESS + PV is not modelled and should have been included for the total overview.

The added value from the hybrid operation is particularly related to charging the batteries when the solar would have been curtailed or there are negative prices in the market, improved performance in the ancillary service market and from saving water by using the batteries for provision of energy services during the ramp-up time for the hydropower plant.

The results from the SHOP model indicates that Magat HyPP, with hybridization of hydropower, PV and BESS can increase the net annual revenues with 4 % in a market with both Day-a-head sales and ancillary service markets (CR and DR).

The reason why it is not possible to capture the demonstrated value now, is that there are currently no Hybrid PPA's available, and each power generation unit have to be registered and is dispatched as separate market participants.

3.5 Value capturing in other markets.

Scatec is developing HyPPs also in other markets. We are looking at an opportunity with an existing hydro power plant where the inflow has been reduced over the past decades, and the reservoir runs dry almost every year. There are now expansion plans for a PV plant, with approximately 50 % of the installed hydropower capacity (24 MW + 29.5 MW). There is existing base load fixed price PPAs which will give high captured prices for solar production in combination with the hydropower production on the base load contract. In addition, it is possible for this hybrid asset to participate in the Southern African Power Pool (SAPP), a merchant market with quite high volatility in the prices. This means that the solar production can provide for saving water for times with high prices, to the morning and evening peaks, and still fulfill the baseload contracts.

Simulations are run for a dry year, a median year and a wet year. Especially for dry years, but also for media years, the hybrid operation of the asset is very beneficial.

The technical development of Energy Management System and real time optimization of hybrid operation at Magat HyPP can be directly used in our new development of HyPPs in other markets.

4 Conclusion

The Magat Hybrid Power Plant in the Philippines exemplifies the potential and challenges of integrating renewable energy sources. While its innovative combination of hydropower, floating solar, and battery storage offers promising energy solutions, the current regulatory landscape poses hurdles. Despite these challenges, the insights and technologies developed at Magat hold significant value for the broader renewable energy sector. For engineers in this field, Magat serves as both an inspiration and a case study, highlighting the importance of adaptability and innovation in the face of regulatory complexities.

The lack of defined regulatory framework for construction of floating solar leads to an increased duration of the development phase, which hence increases the development costs. All energy development projects have some controversy. For Magat FPV, the area use at the reservoir can potentially have impact on fishing activities and boat transportation. Mitigation measures such as avoiding the most important fishing areas and boat transportation routes, in addition to construction of a new quay are found together with the local communities. There are also indigenous people living

around the reservoir, but it is decided to stay out of any communities where there are indigenous people.

Ensuring insurable guaranties for the FPV installations has been possible to do through Ocean Sun's work, with references to standards in aquaculture and offshore installations. These guaranties are essential for financial close of a floating solar project.

The value creation at a HyPP, can only be captured if it is possible to automatically allocating assets to different energy market services. TGS Prediktor has developed a real-time hybrid optimization software tool.

The SHOP model indicates that it is possible to increase the net annual revenues at Magat HyPP by up to 4 % with hybrid operation, compared to stand-alone assets. Unfortunately, the current energy market in the Philippines, where each power generation unit have to be registered and is dispatched as separate market participants, do not allow for the power producer to capture the value the Magat HyPP is providing. Despite this overall conclusion here, we can use the experience and the developed technology in other projects and in other markets. Especially markets with base load contracts or specified load profiles are well suited for implementing HyPPs. Or in other markets with "Blended Renewable & Storage Premium PPA".

The total value creation to the society will include the value of stable energy supply and the reduced need for grid upgrades. These numbers are not within the scope of this study, and we have restricted the value creation only to the possible value to the power producer.

Nevertheless, with Magat HyPP it should be possible to use the physical assets to manage different types of PPA structures, which in practise should turn hydropower storage and BESS storage into a physical hedge to complement the financial hedge of the FPV asset. Another option would be for the three assets to operate virtually independently, with a renewable PPA for the generation, and an optimisation agreement for storage. Or adding a price premium to the energy produced from the renewable asset by valuing-in the flexibility which allows better risk management of the energy.

The unique learning and benefits of developing solutions for concrete, large-scale pilot plants, such as the opportunity at Magat HyPP is essential to the entire energy industry. Our experiences highlight the need for large-scale pilot projects in the development of solutions for HyPPs. We would not have had the possibility to do this work without the financial support from the innovation program, Green Platform Initiative, funded by Innovation Norway, NFR and SIVA.

5 Acknowledgements

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Magat HyPP has been one of the main full scale test cases in the HydroSun project. Nothing of the work would have been possible without the co-operation with the SN Aboitiz (SNAP) organization, with CEO Joseph Yu and the appointed project manager for HydroSun at Magat; Daryl Homer Ramos.

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