Innovation, Sustainability and New Regulatory Approaches to Hybrid Power Systems

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***Abstract*—Hybrid power systems (HPSs) are disruptive innovations. The complexity of their design and market characteristics make their deployment difficult, particularly in dispersed and developing markets. The traditional financial models do not fully account for risks and the design of current regulatory frameworks do not provide incentives for the full development of this technology. The contribution of the paper is twofold. Using the literature on disruptive technologies, it argues that HPSs are disruptive but unsustainable without an appropriate regulatory framework that reduces risks and provides incentives for their deployment. From a financial perspective, the second contribution of the paper lies in conceptually introducing and applying the new concept of decoupled net present value (DNPV) in the HPSs. It shows that the use of the DNPV criterion provides a better evaluation of risks and sustainability of HPSs. Regulators and financial analysts would further enhance the deployment of HPSs should they correctly address the issues related to inadequate regulation and inappropriate treatment of risks.**

Keywords- hybrid power systems (HPS); discounted present value; disruptive technology; regulation; risk; sustainability

I. INTRODUCTION

Hybrid power systems (HPS) are cost-effective new organizational structures combining flexibility, reliability and security, capable of generating energy to satisfy the needs of either small remote, isolated and rural areas or large communities [1]. The declining cost of the technologies used to build a hybrid system, make it attractive for investors, consumers, policy makers, environmentalists and other stakeholders.

A HPS combines the joint operation of two or more energy sources (PV/diesel or wind/gas/hydro, etc.) and uses a mini-grid distribution network to distribute the energy produced to the final customers. The HPS may use a storage system to store energy while demand is low and energy production is high. The voltage and frequency of a mini-grid is set by using multifunctional inverters to convert DC and AC currents and control the generation and storage.

HPS is the result of disruptive innovations in the energy markets. In contrast to sustaining innovations, which are generally incremental in nature and emerge from within established value networks, disruptive innovations are new, drastic processes (technologies) or products that change the established value chain with the appearance of new dynamic players in the market [2].

In the energy market, disruptive innovations are quite risky and as such, markets retard to recognize their financial viability. Hybrid power projects, particularly when destined to rural and/or relatively less wealthy clients, need comprehensive and well-targeted support programs. Moreover, the institutional frameworks and the existing regulations are rarely at the point of technological evolution and they are mostly inadequate. International organizations (World Bank, IFC, EBRD, EIB, etc.) are, in principle, willing to finance eligible projects, particularly in geographical areas that lack energy infrastructure, but they generally ask for more transparent, efficient regulatory and institutional infrastructures and a more enabling business environment [3].

Currently, the existing regulatory frameworks are under thorough overhaul in many industrialized countries (UK, EU, USA, Canada, etc.) and some developing countries are about to consider major changes in their regulatory systems (Ivory Coast, Senegal, etc.). Given the growing importance of HPS worldwide, some questions arise. Do the existing regulations of the electricity industry and the forthcoming ones allow for further development of innovations in the HPS? Do the most well known regulatory frameworks (RIIO in the UK and REV in NY), which serve as examples to other countries that envisage reforming the regulation of their energy markets, address the issues arising from the introduction of hybrid power systems and their potential? In many developing countries, HPS developers unsatisfied with the current regulatory frameworks, are joining regional and national electricity associations to lobby for more favorable regulations and policies to the hybrid power investors [4].

Yet, the current methodologies used to evaluate the financial viability and long-term sustainability of HPSs do not fully account for the multiple risks facing the HPSs. They use a single discount factor to account for risk but this may conceal the subtleties that exist among the various risks and the methods used to manage them. The recent development of a better methodological tool, the decoupled net present value (DNPV), is a better alternative. It makes a more accurate evaluation of risks and allows investors to measure and manage them more efficiently. The main thrust of this tool is to bring awareness of the existence of multiple risks and the use of a single discount factor may lead to wrong evaluation of the HPSs. This tool frames better the current ecosystem of HPSs and deals more accurately with the changes and uncertainties created by disruptive technologies and inadequate regulatory frameworks. The DNPV is building resilience at the initial stages of the evaluation of the HPS and aids to its long-term sustainability[1].

This paper examines the emergence of new disruptive technologies in the power sector, particularly in the HPS, and critically analyzes the economic, financial, regulatory and institutional challenges they are currently facing. Specialists do recognize the importance of HPS as catalysts in the reduction of greenhouse gas emissions (GHE) but by deferring investments in centralized grids and distribution networks, HPSs have gotten little attention in the literature of regulation. Some [5] attribute this lack of interest to the fact that important barriers still exist in the development of HPS, chiefly because of lack of "efficient market mechanisms" and the drawbacks of the current paradigm of unbundled power system prevailing in many (developing) countries.

This paper has four sections. Section II reviews the literature on disruptive technologies and brings to the forefront the arguments that may explain the issues currently facing the HPSs and the factors that may impede their future development. It emphasizes the complexity of the current regulatory frameworks and the need for their prospective streamlining. Section III explains the analytical methodology used to establish the link between regulation, risk and sustainable development with respect to the HPSs. It introduces a new evaluation tool, the Decoupled Net Present Value (DNPV) as a theoretical underpinning to this link and explains the importance of public policies, particularly regulatory and institutional necessary to promote the further development of HPSs. Lastly, section IV concludes.

II. BARRIERS TO HPS DEVELOPMENT

Hybrid power systems (HPS) face a number of barriers that hinder their development. As a disruptive technology, the HPSs have revolutionized the electricity industry but their suitability to remote and sparingly populated areas make their long-term sustainability vulnerable. Government policies and regulations favorable to their development are essential for facilitating their deployment in the areas where it is necessary. Other barriers related to demand side and outdated regulatory frameworks with inadequate pricing structures reduce the bankability of the HPSs and discourage private initiatives.

A. *Disruptive technologies*

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B. *Market Characteristics and Regulatory Policies*

On the demand side, there are lot of uncertainties with respect to load curves and customer demand. They are both difficult to predict and may depend upon factors beyond the control of key stakeholders. Technology and regulation take time to change and customers may be unable to afford electricity generated by the HPSs in areas where the cost of their implementation is high. The figure 1 below shows the barriers to HPSs development due to loads and technological constraints.

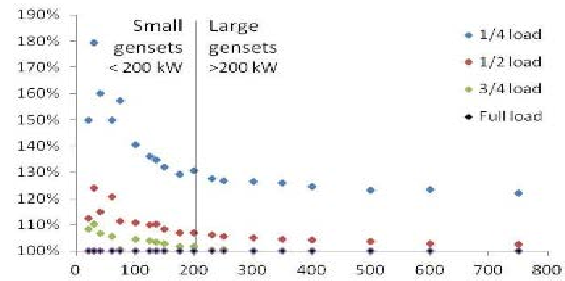

Figure 1: Fuel consumption according to surveyed genset rated power (kW) and actual load

Source: [6]

HPSs are cost-effective new organizational structures combining flexibility, reliability and security, capable of generating energy to satisfy the needs of either small remote, isolated and rural areas or large communities. The declining cost of the technologies used to build a hybrid system, make it attractive for investors, consumers, policy makers, environmentalists and other stakeholders.

As far as regulation is concerned, the existing regulatory frameworks have been designed to promote grid connection instead of off-grid. This combined with uniform tariff structures and a monopoly market design may keep competition at bay and discourage private sector development. HPSs are rather risky and they have difficulties in getting finance from the banking sector, an industry notoriously known as risk averse. Because they are essentially small-scale high-risk projects, their bankability is greatly reduced. In developing countries, international financial institutions provide warranties and other means to make a country's business environment friendlier to investment and promote private initiative by reducing risks and increasing the bankability of various projects [7].

[1] Resilience is a concept used to describe how an individual (firm, organization, etc.) can deal with disturbances and changes (technological, institutional, etc.) in an environment of growing risks and uncertainties to safeguard a more sustainable future.

Various studies have identified the lack of adequate regulation as the most serious barrier to the rapid deployment of HPSs. The main issues concern the current regulatory frameworks and concerns:

1) the definition of the market structure of the electricity industry (a single public utility or multiple players)
2) the role of independent power producers (IPPs), the signing of power purchasing agreements and the jurisdictional responsibilities (Ministry and/or regulatory agency or another entity)
3) the current tariff structure (Subsidies used to curtail price volatility may be incompatible with the development of HPSs. Governments should enact new regulations allowing the introduction of new pricing schemes like FiT programs and/or RE production certificates that make the implementation of HPSs much easier)
4) the codes and standards that allow the integration of RE and the connection to the grid energy storage systems and other electronic power devices.

Conscious of these changes, various regulatory agencies around the world revamped and/or are about to revamp their models of regulation and increase their adaptability. Most of them respond to specific needs of their electricity industry but they fail to address entirely the issues arising from the introduction of hybrid power systems. For instance, the RIIO regulatory model introduced by the UK regulator, Ofgem, or the REV model elaborated by the New York Public Service Commission are viewed as the most advanced regulatory models designed to respond to actual and future needs of consumers and the electricity industry alike. Both are widely hailed as the most innovative regulatory models. They are both empowered by strong incentives capable to incentivize firms and consumers alike to make better decisions. Under RIIO and REV, firms find it profitable to offer better quality services and introduce new production and commercial technologies, while consumers find it rewarding to respond faster to environmental and other challenges facing the economies. Despite their originality, these models suffer in many respects. First, they do not make any explicit reference to HPS and they do not have specific tools to aid their development. Second, both RIIO and REV fail to provide incentives and address adequately the challenges facing the hybrid power systems and treat them as opportunities to meet their environmental objectives and the UN SDGs.

III. METHODOLOGIES USED TO VALUE INVESTMENTS IN HPSS

The financial acceptance of an investment project using hybrid energy is a critical step in its materialization. Financial economists and engineers use various methodologies to determine whether a HPS is financially viable and capable of providing a reasonable reward to investors commensurate with its risk.

The risks are multiple: technological, institutional/regulatory, financial and socio-economic, or related to uncertainties about the market and customers' ability to pay. The combination of two or more energy sources makes the HPSs technologically complex. The lack of sufficient data with respect to both load curves and meteorological characteristics make the design of HPS and their financial evaluation complex.

Risk allocation is an important aspect of any investment project and its design is critical to its financing and eventually to its realization (accept/reject decision). The various methodologies used to evaluate HPSs differ significantly in the way they value risk and its allocation. Actually, the differences lie on the nature of the project, whether it falls in the field of "project finance" or "corporate finance". In the former, it is important to identify each individual risk and to "transfer" it to the ones willing to accept it and able to manage it efficiently. Promoters use the "risk-free" expected cash flows of the project as a warranty to get funds from investors. In the latter (corporate finance), financiers discount the expected cash flows of the project using the market interest rate adjusted for the risk of the project. In this case, risks are rarely singled out and the discount procedure requires an adjustment in the interest rate to account for the risks. Usually, creditors and shareholders share different risks and their compensation is therefore different.

When risks are high, as in the case of HPSs using renewables and conventional technologies, it is rather difficult to attract investors willing to commit their funds to long term sunk[2] and non-sunk assets. Investment in sunk assets may become more attractive if governments provide subsidies, guarantees and/or other financial aid. For instance, Spain, Denmark, Germany and other European countries used the Feed-in Tariffs (FiT) programs and other policies to reduce the cost and make investment in renewables attractive. By virtue of FiTs, investors get a guaranteed price agreed on to prevail for a certain period of time and a market for their product. Mostly, government programs aim at reducing the risks associated with the project and making attractive private investments in infrastructure[3]. Other programs such net metering provide incentives for power generation by individual customers but it has a different impact on risk than the FiT program.

From a financial perspective, researchers use the following criteria to evaluate HPSs: the Net Present Cost (NPC), the levelized cost of energy (LCE) and life-cycle cost (LCC). These methodologies have one characteristic in common; they discount expected cash flows without adjusting them for risk. Usually, researchers use well-established financial models such as the CAPM, APT, etc., to calculate the rate to discount the expected cash flows. Normally, the discount rate is the weighted average cost of capital (WACC) adjusted for risk.

A. Traditional Discounting Methodologies to Evaluate HPSs

The NPC or the life-cycle cost: it calculates the net present value of total costs of a HPS during its life cycle. These costs include all discounted CAPEX (capital and installation costs) and OPEX (replacement, operations and maintenance costs) minus the discounted value of all

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[2] Sunk costs refer to long term and irreversible investments for which an investor has meager possibilities to get back his investment in case of bankruptcy.

[3] There is a debate concerning the suitability of these programs and their contribution to the well-being of society, chiefly with respect to their sheer size and costs.

expected revenues that a HPS can generate during its lifetime to reflect the present value of money.

A simplified formula to calculate the NPC is the following:

$$NPC = \frac{TAC}{CRF} = \frac{TAC}{\frac{r(1+r)^t}{(1+r)^t - 1}} \quad (1)$$

Where TAC is the total annualized cost, i.e., the annualized value of the total NPC and the capital recovery factor (CRF). The r stands for the annual discount rate and t is the useful lifetime of the HPS.

Another formula used to calculate the NPC is:

$$NPC = \frac{TCO(1+i)^N}{1+ROI} \quad (2)$$

Where i is the annual inflation rate, N the cumulative number of years and TCO is the total capital outlay and includes initial capital expenditures, maintenance and replacement costs and operational costs. ROI is the return on investment or a market interest rate.

The NPV and the IRR: another discounted Cash Flow (DCF) approach used to evaluate the financial viability of a HPS is the net present value method and the internal rate of return (IRR). To get the net present value (NPV), we subtract the (upfront) cost of investment from the expected cash flows (CFs) previously discounted using a predetermined hurdle rate (r). A positive NPV contributes to the value of the firm and the investment in HPS should be accepted[4].

$$NPV = \sum_{n=0}^{N} \frac{CF_n}{(1+r)^n} - C_{inv} \quad (3)$$

This general formula is easily adapted to the case of HPSs.

$$NPV = \sum NPV_{sale\_k} + \sum NPV_{end\_k} - C_{inv} - \sum NPV_{r\_k} - \sum NPV_{O\&M\_k} \quad (4)$$

If the HPS is grid-connected, NPV_{sales_k} represents the discounted proceeds from selling electricity to the grid. NPV_{end_k} is the discounted net present value of an item k during its lifetime and NPV_{r_k} are the discounted replacement costs of an item k. Lastly, $NPV_{O\&M\_k}$ are the discounted operation and maintenance costs of an item k over its lifetime.

Another tool used to evaluate whether HPS is economically viable is the internal rate of return (IRR). The latter is a discount interest rate that gives a NPV equal to zero and represents the true interest yield (hurdle rate) offered by the HPS over its lifetime.

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+IRR)^n} - C_{inv} = 0 \quad (5)$$

The LCE (levelized cost of energy): is an estimation of the unit cost of energy that makes investment in HPSs finically viable. This breakeven determination of the investment is critical for its configuration and final design. It is calculated as a ratio of total annualized cost of the components of the HPS to the total annual energy delivered.

$$LCE = \frac{\sum_{n=1}^{N} \frac{I_n + M_n + F_n}{(1+r)^n}}{\sum_{n=1}^{N} \frac{E_n}{(1+r)^n}} = \frac{TAC}{E_{tot}} \quad (6)$$

Where E_n is the annual production of electricity, F_n is the annual expenditure on fuel, I_n is the annual investment, M_n are the annual O&M expenses and r is the discount rate. TAC stands for total annualized cost and E_{tot} for total annual energy generated by the system. Depending on the type of HPS, these parameters may differ significantly. For instance, PV systems' lifespan may be 25 years, while the lifespan of a wind power mill may be 20 to 25 years.

LCC or Life-cycle cost: is another method to calculate the cost of the HPS by taking into account the initial capital cost (IC_{cap}), the present value of replacement cost (C_{rep}) and the operating and maintenance ($C_{O\&M}$) costs. In case there is a salvage value (S) at the end of the project's lifespan, the latter is subtracted.

$$LCC = IC_{cap} + C_{rep} + C_{O\&M} - S \quad (7)$$

Other similar methodologies used to estimate the financial viability of a HPS is the annualized cost of the system and the payback period.

The ACC (annualized cost of the system): is the sum of the annualized capital cost (C_{acap}), the annualized replacement cost (C_{aper}) and the annualized maintenance cost (C_{amain}).

$$ACC = C_{acap} + C_{acap} + C_{amain} \quad (8)$$

The PBP (payback period): refers to the number of years necessary to get back the initial investment in a HPS. Nowadays, researchers use a discounting approach to account for the time value of the investment.

$$PBP = \frac{C_{inv}}{CF_n} \quad (9)$$

Where C_{inv} and CF_n stand for the initial capital investment and periodic cash inflows, respectively.

These techiques use a hurdle rate to discount cash flows. Usually, the Weighted Average Cost of Capital (WACC) serves as a hurdle rate. It is an average rate of two marginal costs weighted by the proportion of each source of financing HPS, usually equity and debt to the total capital, usually equity (E) and debt (D) to total capital cost.

$$WACC = k_e \frac{E}{D+E} + k_d \frac{D}{D+E} \quad (10)$$

[4] In practice, some projects with negative NPVs may be accepted for strategic and/or other objectives.

To calculate the marginal cost of equity financing, one may use the well-known financial model, the CAPM (Capital Asset Pricing Model). According to this model, the value of risky assets depends on the degree of undiversifiable risk. The latter is the risk that remain within the business after managers have adopted the strategy of diversification to eliminate the diversifiable risk. Investors are compensated (get a prime) for the residual risk, which cannot diversify away.

$$E(R_j) = R_F + \beta_j \,(R_M - R_F) \quad (11)$$

Where $E(R_j)$ is the expected return on asset j, R_F is the risk free rate, R_M the return of an index like Dow Jones and beta (β) is the non-diversifiable risk of the asset.

Prior to investing in HPSs, investors need a thorough understanding of all the risks associated with their investment. Financiers use various tools to assess and quantify them. This is importance because investment in HPSs is “sunk” or rather illiquid, and profits may not show up unless the risks are properly evaluated and diversified. Unfortunately, the traditional criteria economists and financial analysts use to take into account the risks of an investment based on the discounting approach (NPV, IRR, etc.) are increasingly being criticized [8]. The gist of the criticism lies on the use of the discount rate. [8] argue that investment in a HPS has various risks and the use of a single discount rate (like the WACC) cannot capture all these risks. The use of a single discount rate may lead to a wrong evaluation of the riskiness of a project and result in over — or under – investment. To get the capital required for an investment, managers must reassure investors, equity owners and creditors, that they will earn at least the WACC of the investment. The NPV criterion is a top-down approach to value investment projects, although a bottom-up approach is more appropriate.

These criticisms led to the development of alternative models like real options, decision analysis and other probability-based methods as better approaches to valuation of risky investments and the development of strategies [9]. These methods have a theoretical appealing but it is difficult to apply them in practice and even more difficult to explain them to decision makers. The latter are rather slow to depart from the traditional tools and reluctant to espouse new ones [10]. Recently, some researchers [8] have proposed a new approach to value risks, the decoupled net present value (DNPV), with the purpose of correcting the deficiencies of the standard methodologies.

B. The DNPV tool

This new valuation methodology uses probabilistic analysis to measure and value risks of energy projects. It uses the option pricing theory to price the costs associated with risks and integrates these costs to the project valuation – a bottom-up approach. The DNPV approach does not refute the traditional NPV method. By pricing risks in this way, the project’s *risk performance* is appropriately evaluated. Nonetheless, managers still need to use the traditional NPV method to measure the *financial performance* of the project by using the unadjusted WACC criterion.

[11] and [12] were the first ones to use neutral and actual probabilities along with decision tree analysis for valuation of risk in oil and gas investment projects. [8] build on these ideas and use risk-neutral probabilities for public, i.e. market risks and actual probabilities for private, i.e., non-market risks. In their modeling, investors are viewed as insurance providers and their compensation reflects all the risks that cannot be diversified away. Therefore, investors’ compensation is viewed as an insurance premium reflecting the risks (private and public) owned by each investor.

[8] illustrate their arguments with a real example for a French solar project but the analysis is equally valid for any energy investment project. The authors adopt a five-step approach to manage risk. [13] used the DNPV method and applied this five-step approach to evaluate renewable energy investment projects in Germany. The five-step approach is as follows:

1) identify and understand the risks of the project;
2) select risk ownership and identify the risks sharing procedures;
3) determine the risk tolerance and quantify the amount of acceptable risk;
4) choose the risk mitigation mechanisms; and
5) monitor and manage risks.

To make a sound valuation of an investment project, the first important step is to identify the risks of the project. Traditionally, neutral and actual probabilities are identified for each of the project’s risks and using the decisions tree analysis the future outcomes are pinpointed in each of the branch of the tree. The mapping of future outcomes with the attached probabilities becomes extremely complicated as soon as the number of identified risks becomes important. The DNPV rule uses an integrated i.e., holistic approach. Although risks can be integrated in a number of different ways, according to the DNPV method, their integration should be in harmony with the firm’s risk management, financial, operational and strategic objectives. The five-step approach mentioned above is thus important in pricing the risks and the valuation of the project.

IV. Conclusions

Hybrid power systems (HPS) are new promising organizational structures combining flexibility, reliability, security and relative easiness to install and generate energy to satisfy the needs of either small isolated areas or big geographic areas.

The deployment of HPSs can be further increased should the traditional financial models could fully account for risks and make better valuations of the profitability of investments in HPSs. This paper argued that the new financial tool, the decoupled net present value (DNPV), is more appropriate to value risks when disruptive technologies create opportunities for new business models that contribute to society (reduce pollution, provide a service where previously was not possible, etc.) but are unsustainable in the short run. In addition, the existing regulatory barriers limit the further expansion of HPSs.

The design of current regulatory frameworks has evolved without taking into consideration the full development of this technology. Without an appropriate regulatory framework that reduces risks and provides incentives for the deployment of HPSs, the UN SDGs (United Nations Sustainable Development Goals) may not be met. Regulators and financial analysts would further enhance the deployment of HPSs should they correctly address the issues related to inadequate regulation and inappropriate treatment of risks.

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