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Online Optimization for the Smart (Micro) Grid

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Abstract: Growing environmental awareness and new government directiveshave set the stage for an increase in the fraction ofenergy supplied using renewable resources. The fast variationin renewable power, coupled with uncertainty in availability,emphasizes the need for algorithms for intelligentonline generation scheduling. These algorithms should allowus to compensate for the renewable resource when itis not available and should also account for physical generatorconstraints. We apply and extend recent work in the_eld of online optimization to the scheduling of generators insmart (micro) grids and derive bounds on the performanceof asymptotically good algorithms in terms of the generatorparameters. We also design online algorithms that intelligentlyleverage available information about the future,such as predictions of wind intensity, and show that theycan be used to guarantee near optimal performance undermild assumptions. This allows us to quantify the bene_tsof resources spent on prediction technologies and di_erentgeneration sources in the smart grid. Finally, we empiricallyshow how both classes of online algorithms, with orwithout the predictions of future availabilitysigni_cantlyoutperform certain `natural' algorithms..

Keywords: optimal, micro grids, algorithm, generation scheduling, optimization,

1.Introduction:

Growing environmental awareness and government directiveshave set the stage for an increase in the fraction of electricitysupplied using renewable sources[1]. Distributedgenerationespecially solar and wind power collectedPermission to make digital or hard copies of all or part of this work forpersonal or classroom use is granted without fee provided that copies arenot made or distributed for profit or commercial advantage and that copiesbear this notice and the full citation on the first page. To copy otherwise, torepublish, to post on servers or to redistribute to lists, requires prior specificacross di_erent small generation locations, is gaining considerableimportance and their deployment is perceived asvital in achieving carbon reduction goals [2].Extractingthe maximum value from a time varying and intermittentrenewable energy resource requires intelligent scheduling ofboth generation and loads Intelligent generation scheduling (involving unit commitmentand economic dispatch), is the process ofscheduling di_erent generation sources to minimize cost whilemeeting physical constraints of the electricity system. It is ahighly non-linear problem,andusuallysolvedusinggeneticprogrammingorothe rnonconvexoptimizationtechniquesConventionaleconomic dispatch,averywellresearchedmethodology, is typically conducted 24 hours in advance (of-ine, day ahead) and uses the fact that the system load canbe reasonably well predicted a day in advance. However,in a (micro) grid with high levels of wind penetration, thisno longer holds due to the intermittent and unpredictablenature of wind power (which can only be reliably predicteda few minutes in advance). This introduces practicalchallenges such as the ramping constraints, which limit howfast a generation source can increase or decrease its outputover successive steps. Thus, the need for designing techniques,with a _rm theoretical basis and worst case guarantees,that enable

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online generation scheduling subject tosuch physical constraints becomes very important, and ourwork is a major step in bridging this gap in literature.Recent advances in wind prediction _er hope thata reduction in the uncertainty of wind availability will leadto an increaseinitsvalue.Onlineversionsofgenerationschedulinghavebeenstudiedrecently Thesealgorithms,almostinvariably, make assumptions regarding the stochasticnature of wind resources. For example, Xie and Ilic use Model Predictive Control (MPC) for economic dispatch,where a model is constructed that predicts future renewableavailability (assuming that the availability arises from somestochastic process) and then this prediction is used for generatoroptimization. These methods are computationallycomplex but seem to be e_ective in practice. This raisessome interesting questions that motivate this paper (i) Arethere computationally simple algorithms that are still provablye_ective undernon-stationaryorarbitraryrenewableavailability? (ii) Can we build a theoretical basis for thesuccess of these online and MPC based algorithms? (iii)Can we use the theory to design algorithms that optimallyincorporate available information about the future ?We address these issues in the context of intelligent onlinegenerator scheduling in microgrids with large, unpredictable.

1. We demonstrate how, even in the harsh scenario whereno prediction of the future is available and wind availabilityis chosen in a n arbitrary manner, recent advancesin online convex optimization[3]. can be fruitfullyapplied to generator scheduling in the next generationof smart (micro) grids. We also show how to exploitthe special structure of the cost function for generatorscheduling to obtain performance guarantees interms of parameters governing the generation sources.

2. We describe online algorithms[4]. that leverage informationabout the near future, such as prediction ofwind availability and intensity moree_ectively.Interestingly,thesealgorithms use a strategy that discountsthe future costs appropriatelyinorderto proveguaranteesonun-discounted future performance.

3. We extend the work in online optimization to prescribecomputationallysimpleonlinealgorithms that modelpractical constraints of the generation sources, such asramping constraints and multiple generation sources.

4. We empirically show how both the classes of onlinealgorithms,i.e.withorwithoutlookahead,signcantlyoutperformtheexisting `natural' algorithms in the literature.For example, we show that discounting thefuture costs (perhaps counter-intuitively) can outperformalgorithms with lookahead that do not discountthe future. Thus, the theoretical techniques can beused to inform algorithm design.Our work conclusively establishes the value of the proposedonline algorithms and their theoretical analysis for the smartgrid. The results equip us with a strong theoretical frameworkto quantify the bene_ts of resources spent on predictiontechnologiesand multiple generation sources in the smartgrid. While our algorithms can be used for both generator.

2.The experimental microgrid system:

The composition of the microgrid system is shown in Figure 1, along with a photo of the actual installation. It is a modular system, comprising a PV generator as the primary source of power. The addition of a small WT is also planned for the immediate future (it is expected to be connected and operating before the final paper is submitted). Both microsources are interfaced to the 1-phase AC bus via DC/AC PWM inverters. A battery bank is also included, interfaced to the AC system via a bi-directional PWM voltage source converter[5]. The microgrid is connected to the local LV grid, as shown in Figure 1.

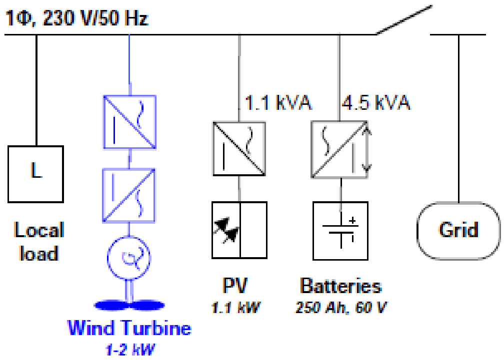

Figure 1: The laboratory microgrid system (WT extension planned for next semester)

The central component of the microgrid system is the battery inverter, which regulates the voltage and frequency when the system operates in island mode, taking over the control of active and reactive power. The battery unit power electronics interface, schematically illustrated in Figure 2, consists of a Cuk DC/DC converter and a voltage source PWM inverter, both bi-directional, permitting thus charging and discharging of the batteries. The DC/DC converter provides the constant 380 V DC voltage to the DC/AC converter input. The HF transformer, operating at 16.6 kHz, provides electrical isolation between the battery bank and the grid. The four-quadrant DC/AC converter comprises a single phase IGBT bridge, output filters and a grid-connection inductor[5].

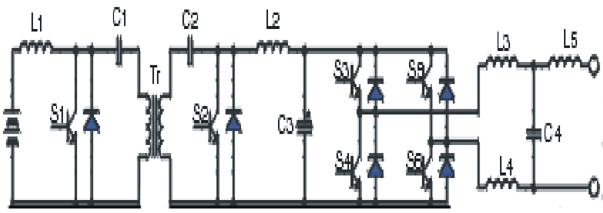

Figure 2:. Power section of the battery inverter

The battery inverter operates in voltage control mode (regulating the magnitude and phase/frequency of its output voltage), acting as a “grid-forming” unit, when the microgrid operates in island mode, i.e. setting the voltage and frequency of the system. When the microgrid operates in parallel to the grid, in which case the latter defines the operating frequency and voltage, the inverter operates as a “grid-following” unit. The PV inverter performs the MPPT function of the photovoltaic generator and operates as a “grid-parallel” unit, responsible for maximizing the PV power output, but without any participation in the voltage or frequency regulation.

3. THE MICRO-GRID CONCEPT :

A microgrid can be simply defined as an aggregationof electrical generation, storages and loads. The generators in the microgrid may be microturbines, fuel cells, reciprocating engines, or any of a number of alternate power sources. A microgrid may take the form of shopping center, industrial park or college campus. To the utility, a microgrid is an electrical load that can be controlled in magnitude. The load could be constant, or the load could increase at night when electricity is cheaper, or the load could be held at zero during times of system stressDistributed Generation DG refers to the numerous small, modular electricity generators, preferably new and renewable energy technologies which are located at LV lines, often close to the point of end use. Concept of MicroGrid supersedes all the advantages of single source DG and hybrid DG. Moreover, it also includes all the advantages of networking, at mini scale. A microgrid combined with power electronic interface is a completely self-sufficient network, with preferably autonomous control, communication and protection. It is capable of providing capacity support to the transmission grid while in grid-connected mode, and with capacity in excess of coincident peak demand. So, the Micro grids comprise low voltage LV distribution systems with integration of Diverse Energy Resources DER such as photovoltaic, wind, bio-mass, bio fuel and fuel cell together with Distributed storage DS like flywheels, energy capacitors and batteries and Controllable Loads that behave as a coordinated entity networked by employing advanced power electronic conversion and control capabilities A schematic diagram is shown here for two types of microgrids: (i) Utility type microgrids which contain parts of the utility main grid and other one the (ii) industrial/commercial type microgrid which only include customer facilities[6].

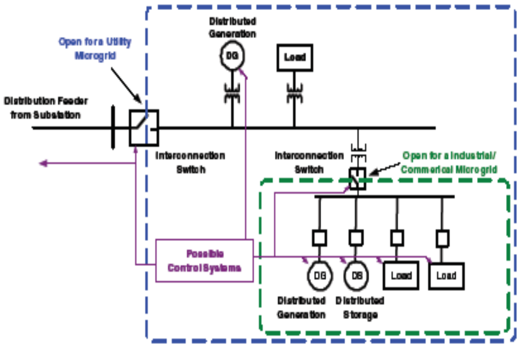

Figure 3: microgrid systems overall performance

There are many potential benefits to customers from the use of microgrids including improving reliability by providing power to the islanded portion of the electric power system (EPS) during a utility outage and resolving power-quality issues by reducing total harmonic distortion at the loads. Distributed storage (DS) technologies are essentially used in microgrid applications as the renewable generation and loads of the microgrid cannot be exactly matched. Distributed storage provides a bridge in meeting the power and energy requirements of the microgrid. Distributed storage enhances microgrid systems overall performance in three ways[6]. First, it stabilizes and permits DG units to run at a constant and stable output, despite load fluctuations. Second, it provides the ride through capability when there are dynamic variations of primary energy (such as those of sun, wind, and hydropower sources). Third, it permits DG to seamlessly operate as a dispatchable unit.

4. MICRO GRID RESEARCH PROJECTS :

A key feature of microgrids is that they can comprise of a variety of generation and loads. To accurately test these systems, a multifunction laboratory is needed that integrates generation, storage, and loads, as well as electrical and thermal capabilities[7]. There are a number of active Micro Grid projects around the world involved with testing and evaluation of these advanced operating concepts for electrical distribution systems. The Micro Grid research based on simulation study and hardware laboratory projects currently in progress to conduct field tests on Micro Grid applications are in Europe, the United State, Japan, Canada and India [8].

4.1.Microgridprojectatthe National Technical University of Athens (EU):

In the European Union (EU), the project was led by the National Technical University of Athens (NTUA) Greece together with research institutions and universities. The project was involved on simulation and demonstrates Micro Grid operation on laboratory scales. The laboratory-scale microgrid system, installed at the National Technical University of Athens, comprises two PV generators, one wind turbine, a battery energy storage, controllable loads and a controlled interconnection to the local LV grid. The battery unit, the PV generators and the wind[9].
turbine are connected to the AC grid via fast-acting DC/AC power converters. The battery converter in particular is suitably controlled to permit the operation of the system either interconnected to the LV network (grid-tied), or in stand-alone (island) mode, with a seamless transfer from one mode to the other. The configuration of the microgrid system installed at the National Technical

University of AthensisshowninFig.

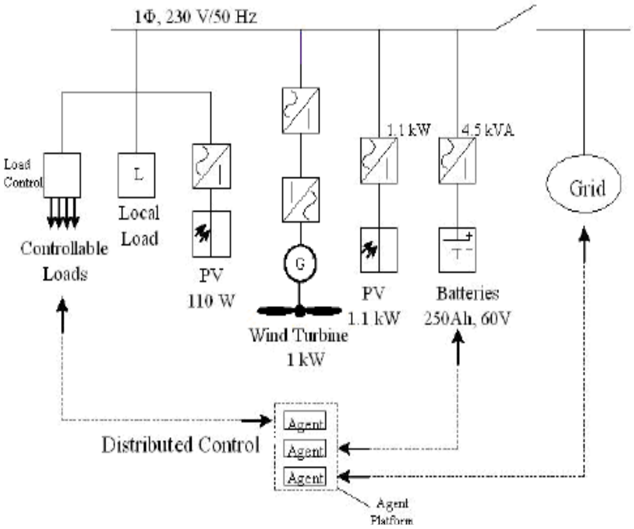

Figure 4: configuration of the microgrid system distributed control

The project was successfully completed providing several innovative technical solutions, which include the development of islanded and interconnected operating philosophies, local black-start strategies, and grounding and protection schemes, methods for quantification of reliability benefits. The other achievements of this project are to standardize the technical and commercial protocols and hardware to allow easy installation of distributed generation with plug and play capabilities. Other EU demonstration sites are taking place in Netherlands, Germany, Denmark and Spain.

4.2.Microgrid project CERTS by the US Department of Energy & California Energy Commission:

The R&D activities in the United State on Micro Grids research programme was supported both by the US Department of Energy & California Energy Commission[10]. The most well-known US Micro Grid R&D effort has been pursued under the Consortium for Electric Reliability Technology Solution CERTS which was established in 1999. The CERTS Micro Grid is intended to separate from normal utility service during a disruption and continue to serve its critical internal loads until acceptable utility service is restored. Actually, the function provided by the CERTS Micro Grid is purposely to save cost and no single device is essential for operation, creating a robust system. The reliability of the CERTS Micro Grid has been well demonstrated in terms of simulation and the bench testing of a laboratory scale test system at the University of Wisconsin, Madison. Full-scale testing on the CERTS Micro Grid concept has been installed at the Dolan Technology Center in Columbus Ohio, which is operated by American Electric Power. Figure below illustrates the CERTS microgrid design with protected critical load circuits and unprotected traditional load circuits.

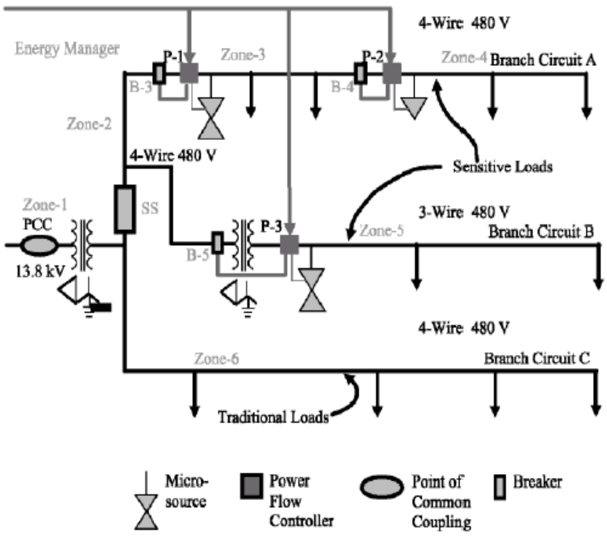

Figure 5: below illustrates the CERTS microgrid

The CERTS Micro Grid has presents unique electrical analysis challenges such as contain three phase, single phase and variety of sources interconnected by power electronic devices employing different control approaches. The modeling approach enables analysis of a variety of issue such as prediction and evaluation of imbalance, asymmetries, generation-load control and dynamic voltage.

5. Simulations:

We now consider some simulations to quantify the bene_tsof lookahead and also to highlight some interesting di_erencesbetween the future discounted analysed above and theundiscounted = 1 version. Recall that the undiscountedversion was suggested for generator scheduling in.For the purpose of the simulation we consider a simplewind power availability pattern shown in Figure 6. We consider

the performance of 3 algorithms on this pattern (i) theOCO algorithm from Section 4 (ii) the future discountedalgorithm with lookahead from Section an algorithmthatconsiderstheoptimalgenerationschedulewith

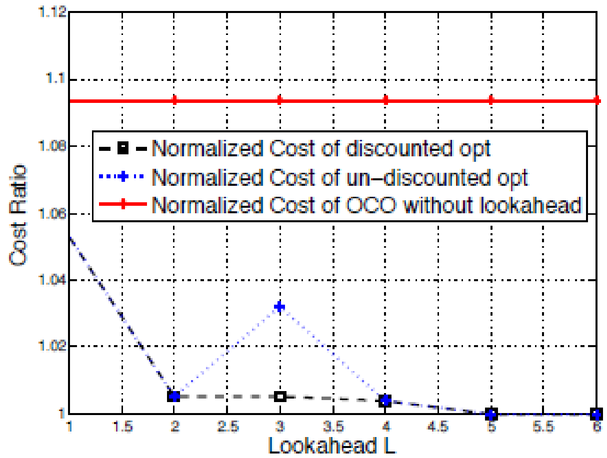

Figure 6: A comparison of the performance of (i) the OCO algorithm from Section

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the same lookahead but without a discounting factor. Theresults of the of the simulation is in Figure 6 From we see that the performance of the OCOalgorithm is reasonable even without any lookahead. Onevery interesting observation is that the performance of the
`default' scheduling with lookahead algorithm that does notdiscount future rewards is non-monotonic in the amount oflookahead. That is in some cases the performance of thealgorithm may become worse with increasing lookahead[11]. InFigure 6 this corresponds to increasing the lookahead from 2to 3. Here the performance degrades at lookahead 3 becauseof the particular periodicity inherent in the signal in Figure3. However, the same degradation is observed at di_erentlookahead with the wind patterns in Figure 6. However, thefuture discounted algorithm with optimal performs wellacross the di_erent lookahead lengths.

7. CONCLUSION:

In this paper we have demonstrated that the theory andalgorithms developed for online optimization are useful forgenerator scheduling problems in the smart grid, with suitableextensions to account for practical constraints such asgenerator parameters and ramping constraints. We designedsimple algorithms, derived guarantees on their performanceunder mild assumptions and showed that they perform well
even when no predictions of the future are available. Weshowed how to incorporate predictions of the future renewableavailability e_ectively into online generator schedulingalgorithms, and quanti_ed the bene_ts of lookahead. Interestingly,we showed that discounting the future is usefulboth as a proof technique and as a strategy for generatorscheduling with ramping constraints.In addition to load scheduling for cost minimization basedon reviewer comments we are particularly interested in understandingonline optimization algorithms for other applicationsincluding voltage support, distribution losses, andenergy storage management that are particularly importantin smart grids with a large penetration of renewable energy.Finally, on a theoretical side new online algorithms or timevarying discounting strategies that have better performance
guarantees would be an interesting direction of future research

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