Notes on security of electricity supply, some practical problems in MV/LV networks and legal aspects of building global grid

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This documents presents a note on security of electricity supply and several short notes on some technical problems in MV/LV networks and legal aspects related to building global grid. The only aim of the document is to provide potentially useful material for those interested in the problems (particularly those at initial stage of their research). Considered problems include:

1. **Security of electricity supply,**
2. **Approaches for optimal placement of DGs and EV's charging stations,**
3. **Approaches for corrective measures (load flexibility and generation curtailment) in LV networks,**
4. **Approaches to infer LV network model from smart meter data,**
5. **Approaches for phases balancing in LV networks,**
6. **Approaches for voltage and thermal overload control in active distribution networks, and**
7. **Legal aspects related to building Global Grid.**

1. Security of electricity supply

A short review of existing literature

An extensive search of existing literature reveals that the security of electricity supply is considered either as an integral part of the overall security of energy supply [1,2] (considering diverse primary energy sources such as gas, oil, electricity, etc.) or separately based on the concepts of power system reliability [3,4,5,6] and resilience [7]. A number of indicators have been proposed to measure power system reliability (with its two ingredients: adequacy and security). These indicators measure the risk of electricity supply interruptions in terms of size, duration and probability. Some of most popular indices include: System Average Interruption Duration Index (SAIDI), Loss of Load Expectation (LOLE), Loss of Load Probability (LOLP), Expected Energy Not Supplied (EENS), etc. [3,4,5]. The indicators are computed as deterministic [3] or probabilistic [4] while well-being analysis framework [5] provides a bridge between the deterministic and probabilistic approaches using the operating states designated as healthy, marginal and at risk. Power system vulnerability [6] is often used interchangeably with the reliability (actually the term vulnerability appeared to also indicate importance of cyber security of power system but often refers, as in [6], to the system reliability). The concept of power system resilience [7] refers to catastrophic rare system events (caused for example by extreme weather and natural disasters).

Reference [1] suggests that the concept of reliability is also major approach to analysis and assessment of security of electricity supply when considered as an integral part of the overall security of energy supply. Work presented in [2] proposes and interesting approach to overall security of energy supply analysis and assessment that could be used in the security of electricity supply as its integral part. It extends a promising approach known as the "four As of energy security (availability, accessibility, affordability, and acceptability)". Concept of energy security as "low vulnerability of vital energy systems" was introduced [2]. This approach opens the road for detailed exploration of vulnerabilities as a combination of exposure to risks and resilience and of the links between vital energy systems and critical social functions [2].

Work presented in [8], based on ENTSO-E generation balances capacity concept (derived from the concept of reliability), developed the notion of so-called secured capacity. A capacity balance allows for a general overview of electricity peak demand and the contribution of each energy source to cover that demand while secured capacity results from a combination of several probabilistic distributions on the availability of each type of generation capacity [8]. The approach considers only one dimension of the security of electricity supply problem stemming from the concept of reliability (or more precisely generation adequacy). The results are provided for German power system considering electricity supply from intermittent resources but without consideration of power imports.

Reliability is just one dimensions of the security of electricity supply. Recognizing this, reference [9] proposed an approach based on three dimensions of the problem: reliability (adequacy and security), firmness, and strategic energy policy. These dimensions mostly determine system configuration, market structure, and resource utilization [9]. A hydrothermal scheduling model that incorporates DC power flows, generation expansion decisions, and a detailed bilateral contracting structure, which Icelandic generators and consumers typically use for arranging power prices and negotiated curtailments have been developed [9].

A 9-dimensional framework for security of electricity supply, with specific reference to the situation in Japan, was presented in [10]. The dimensions of the security of electricity supply considered are [10]: (1) imported energy resource dependence, (2) imported fossil fuel dependence, (3) diversification of energy resources, (4) supply system reliability, (5) power generation efficiency, (6) global warming potential, (7) terrestrial acidification potential, (8) particulate matter formation, and (9) generation of radioactive waste.

The framework that includes 12 dimensions that are critical for security of electricity supply is proposed in [11] with the metrics that capture the state and evolution of each dimension. The framework is intended to be a management information tool for all stakeholders, aimed at organising data and structuring its analysis, to enable monitoring the evolution of the security of electricity supply, while also functioning as an early-warning system by flagging potential future problems. The problem dimensions include [11]: generation adequacy, resilience, reliability, supply flexibility, grid conditions, demand management, regulatory efficiency, sustainability, geopolitics, socio-cultural factors, access, and terrorism. Work of [12] applies a cross impact analysis to these 12 dimensions to determine the degree to which the different dimensions depend on each other. From this an influence diagram to visualise the interdependencies and a scatter plot to categorise the dimensions as independent, driver, connector or outcome is derived. Actions targeting the drivers or connectors are potentially the more effective ones a regulator can take, as the consequences will gradually ripple through the system. Having an integral view of the dimensions' interdependencies provides a better understanding of the higher-order changes an intervention may cause. This enables policymakers and regulators to identifying where in the system to intervene to achieve the desired effect with the least amount of resources and with as few undesirable side-effects as possible.

With specific reference to the context of the European Union, reference [13] provides a rather comprehensive framework for security of electricity supply analysis and assessment. The main suggestions stemming from the research presented in [13] can be summarized as follows:

- Security of electricity supply is multifaceted problem (multi-treat, multidimensional, multi-time, and multi-spatial),
- Security of electricity supply is multi-property problem (operational security, adequacy, resilience, robustness). Reliability is noted as the property covering operational security and adequacy while vulnerability is noted as the property covering resilience and robustness.
- Models used in security of electricity supply assessment should include a combination of different system models (static, dynamic, electricity market) with varying representation of the system details depending of a time-horizon of the analysis.
- Security of electricity supply safeguard actions include: Operational actions (generally short-term): transient/dynamic stability management, pre-fault and post-fault remedial actions (based on contingency analyses) and system balancing, Operational planning and scheduling actions (generally mid-term): forecasting, power scheduling, ancillary service procurement, outage coordination and asset management, Planning actions (generally long-term): system (network) optimisation, enhancement and expansion, and Strategic energy planning actions (generally long-term): strategic energy planning/provision and wide ranging policy and regulatory initiatives (impacting the energy system beyond the electricity system).

An observation: Literature review also reveals that there is no general consensus on the terminology used in both overall security of energy supply and security of electricity supply (an example is term “vulnerability” which somewhere in the literature refers to a system reliability while in some other refers to resiliency and robustness or even only to the dependency of electric power imports). Reaching a consensus on the terminology would certainly facilitate understanding of specific approaches and exchange of research and practical ideas.

Measures to increase security of electricity supply include:

- All above mentioned actions considered in reference [13],
- Reducing the risk of system failures through diversity. This diversity does not refer only to diversity in electricity generation sources but also includes spatial (geographical) diversification and the use of diverse energy storage options. This is sometimes referred to as redundancy in generation.
- Critical infrastructure (transmission and distribution networks) enhancement through reinforcement and expansions. This is sometimes referred to as redundancy in transmission and distribution.
- Demand response as an important security of electricity supply ingredients.
- Development of new algorithmic solutions to analyse and assess security of electricity supply together with deciding on measures to its increase (with focus on dynamic (temporal) nature of the problem instead static (at one moment in time) present in most existing considerations).
- Development of new regulatory framework that will encourage cooperation among power utilities in case of electricity crisis. This development together with redundancy in transmission and distribution network will give new momentum for development of super-grids and the global grid to facilitate this cooperation.

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2. Survey of approaches for optimal placement of DGs and EV's charging stations

Literature survey on optimal placement (or siting) and sizing of distributed generation offers a large number of publications including some review papers [1,2,3]. The problem is considered either solely as the placement problem or both placement and sizing of distributed generation are considered with different objectives (DG penetration maximization, reliability optimization, loss, minimization, etc.). Review papers [1,2,3] reveal the following approaches to solve the problems of placement and sizing: linear programming, optimal power flow, multiobjective optimization, metaherustics approaches (genetic algorithms, fuzzy genetic algorithms, simulated annealing, particle swarm optimization, probabilistic methods (to account for uncertainties), etc.). More details are available in the review papers [1,2,3].

Approaches presented in [4,5] proposed the use of repeated power flow computations to maximize DG generation. It computes available capacity (location and size) for DG connections for present situation taking into account future system developments. This is achieved through receding horizon implementation where the computations are repeated periodically (taking into account developments in the system taken place in the meantime) or as soon as a new DG connection is realized on the distribution system.

Most of existing approaches compute DG available capacity from distribution system operator viewpoint. Reference [6] took also into account the interests of DG owner. The problem naturally fits into the multiobjective optimization framework and in [6] the problem I solved using particle swarm optimization. Work presented in [7] considered modelling the deployment of renewable energy production capacities in the scope of the energy transition. The deployment of technologies is seen as an energy investment under the constraint that an initial budget of non-renewable energy is provided. Using the Energy Return on Energy Investment (ERoEI) characteristics of technologies, a discrete-time formalization of the deployment of renewable energy production capacities was proposed. The model also underlined the potential benefits of designing control strategies for optimizing the deployment of production capacities, and the necessity to increase energy efficiency.

Comparatively less publications exists (as compared to the DG placement and sizing) dedicated to optimal placement and sizing of electric vehicles charging stations. A repeated power flow computations were proposed in [5] to this purpose. The computations are performed in a similar way as for DG placement and sizing with the difference in bus injection increase direction.

In [8] the optimal sites of EV charging stations are first identified by a two-step screening method with environmental factors and service radius of EV charging stations considered. Then, a mathematical model for the optimal sizing of EV charging stations is developed with the minimization of total cost associated with EV charging stations to be planned as the objective function and solved by a modified primal-dual interior point algorithm.

Formulations, complexity and some solutions for charging stations placement were discussed in [9]. Four methods are proposed: iterative mixed-integer linear programming, effective mixed-integer programming, greedy approach, and chemical reaction optimization. The results revealed the methods have their own characteristics and they are suitable for different situations depending on the requirements for solution quality, algorithmic efficiency, problem size, nature of the algorithm, and existence of system prerequisite.

Works presented in [10,11] consider jointly the problems of DG and electric vehicles charging stations optimal placement and sizing. Reference [10] solves the optimization problem focusing on reducing active power losses, improving voltage stability of the system and reducing charging costs of electric vehicles. In order to increase the network load factor some coefficients are introduced. Such coefficients, which depend on wind speed, solar irradiance and hourly peak demand ratio in the load characteristic of day-ahead, help aggregators to charge their EVs in off-peak hours. Differential evolution algorithms are used for solving the optimization problem. Reference [11] introduces a comprehensive optimization method to jointly optimize DG, electric vehicles charging stations together with energy storage. The proposed optimization model is formulated as a second order conic programming problem, considering also the time-varying nature of DG generation and load consumption, in contrast with the majority of the relevant studies that have been based on static values.

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3. Survey of approaches for corrective measures (load flexibility and generation curtailment) in LV networks

Work presented in [1] provides an in-depth review of methods and strategies proposed to prevent overvoltage in LV grids with PV, and discusses the effectiveness, and their advantages, and disadvantages. Based on the mathematical framework presented in the paper, the overvoltage caused by high PV penetration is described, solutions to facilitate higher PV penetration are classified, and their effectiveness, advantages, and disadvantages are illustrated. The investigated solutions include the grid reinforcement, electrical energy storage application, reactive power absorption by PV inverters, application of active medium voltage to low voltage transformers, active power curtailment, and demand response. Coordination between voltage control units by localized, distributed, and centralized voltage control methods is compared using the voltage sensitivity analysis.

Joint voltage/thermal overloads management problem in LV networks was considered in [2,3]. Focus of reference [2] is control of electric vehicles charging points to manage voltage and thermal overloads problems. The infrastructure needed for the control include: voltage sensors and actuators at the charging points, communication links, voltage and current sensors at the head of the LV feeders, and a programmable unit at the substation to host the control algorithm. No direct information such as the state of charge from the electric vehicles is required. The control is essentially hierarchical (feeder level and transformer level) based on P-controllers which gains take into account this hierarchical nature. A key feature of the proposed control strategy corresponds to its corrective and preventive approach to disconnect and reconnect electric vehicles, respectively. This provides an adequate balance between the mitigation of technical problems and the comfort of electric vehicle users. Reference [3] proposed an agent based hierarchical architecture. The approach combines local voltage control mechanism with a centralized (and coordinated) congestion management scheme (based on active power curtailment mechanism).

Smart loads, equipped with converters, were shown to be able to solve voltage problems in LV network in [4]. Limitations of the previously reported smart load configuration with only series reactive compensator (one converter) is highlighted in [4]. To overcome these limitations, an additional shunt converter is used in back-to-back configuration to support the active power exchanged by the series converter, which increases the flexibility of the smart loads without requiring any energy storage.

A systematic method for determining the active- and reactive-power set points for PV inverters in residential systems is proposed in [5], with the objective of optimizing the operation of the distribution feeder and ensuring voltage regulation. Binary PV-inverter selection variables and nonlinear power-flow relations render the optimal inverter dispatch problem nonconvex and NP-hard. Sparsity-promoting regularization approaches and semidefinite relaxation techniques are leveraged to obtain a computationally feasible convex reformulation.

References [6,7,8] considered active power curtailment to manage voltages in LV networks. An adaptive droop-based approach using adaptive dynamic programming is proposed in [6] as a possible solution to minimize the total energy loss in the system while keeping the system voltage under the critical operating limits. A new real power capping method to prevent overvoltages by adaptively setting the power caps for PV inverters in real time was proposed in [7]. The proposed method can maintain voltage profiles below a pre-set upper limit while maximizing the PV generation and fairly distributing the real power curtailments among all the PV systems in the network. As a result, each of the PV systems in the network has equal opportunity to generate electricity and shares the responsibility of voltage regulation. The method does not require global information and can be implemented either under a centralized supervisory control scheme or in a distributed way via consensus control. The work of [8] proposed a local voltage regulation technique that utilizes very short-term (15 s) PV power forecasts to circumvent imminent upper voltage limit violation or an overvoltage scenario. To provide these PV generation forecasts, a hybrid forecasting method is formulated based on Kalman filter theory, which applies physical PV generation modelling using high-resolution (15 s) data from on-site measurements. The proposed algorithm employs an active power curtailment based on these PV power forecasts, when the reactive power estimate given by a droop-based method cannot provide the desired voltage regulation within predefined power factor limits. The curtailment threshold values are calculated in such a way that this voltage regulation technique can reduce possible voltage limit violations.

A distributed control scheme is proposed in [9]. The scheme adjusts the reactive and active power output of inverters to prevent or alleviate overvoltage problems. The proposed scheme is model-free and makes use of limited communication between the controllers, in the form of a distress signal, only during emergency conditions. It prioritizes the use of reactive power, while active power curtailment is performed only as a last resort.

A sequential decision making problems that may soon be encountered within electricity prosumer communities were addressed in [10]. The advantages and disadvantages of centralised and decentralised schemes were discussed and illustrations of decision making strategies provided, allowing a prosumer community to generate more distributed electricity (compared to commonly applied strategies) by mitigating over- voltages over a low-voltage feeder.

Reference [11] extends the control scheme of [9] to the case of unbalanced three-phase four-wire distribution networks with single- and/or three-phase inverters. The control scheme works by first partitioning the inverters into four groups, three for the single-phase inverters (one for each phase), and one for the three-phase converters. Each group then independently applies a distributed algorithm similar to the one presented in [9]. Their performance are compared to those of two reference schemes, an on-off algorithm that models the default behaviour of PV inverters when there is an overvoltage, and the other one based on an unbalanced OPF. Its resulting total curtailed energy always lies between the two, with the on-off algorithm presenting the poorest performance, and the proposed algorithm losing its edge when the network is strongly unbalanced.

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4. Survey of approaches to infer LV network model from smart meter data

Existing approaches mainly deal with a part of the problem of inferring a model of LV distribution network, i.e. inference of its topology.

Reference [1] proposed the smart meter readings (or Advanced Metering Infrastructure (AMI) readings)) mapping to transformer approach to auto generate (infer) LV (or secondary network) topology and impedances. Voltage and KWh readings from AMI were used in the algorithm based on linear regression and basic voltage drop relationships. The proposed approach is able also to infer unmetered loads in LV network.

The application of principal component analysis (PCA) with its graph-theoretic interpretation was proposed to infer LV network topology, including the load phase connectivity, based on time series of energy measurements from smart meters was proposed in [2].

An algorithm based on correlation analysis with Fisher Z transform to infer LV network topology was introduced in [3]. A simple method to estimate network impedances, based on a least-square fit to the power against voltage relation for so-called installation control point to transformer impedance and on maximising of correlation coefficients for branch impedances, has been presented.

References [4,5,6] proposed and analysed some approaches to infer LV network topologies from AMI historical voltage and power measurements. The algorithm uses linear approximation of voltage drop over a series impedance. The algorithm processes one secondary circuit at a time initialized with the list of all the meters of the secondary circuit and an empty mock circuit. For each meter pair at each iteration, the algorithm solves a linear regression problem for the parallel circuit type. The algorithm is shortly introduced in [4] with more detailed elaborations presented in [5,6]. Reference [5] deals with improvements of some existing models of LV networks using inference from smart meter measurements.

Some machine learning approaches were proposed in [7,8,9,10] to infer phase connectivity and topology of LV networks. In this respect, the performance of supervised, semi-supervised and unsupervised techniques were assessed using voltage time series measurements collected from customer smart meters as the feature set for training classifiers. More precisely, support vector machines, label propagation and K-MEANS algorithms were discussed. Approach of [9] suggest that the phase connectivity can be inferred using voltage measurements only. Work presented in [10] further extends the approach by exploiting the DER flexibility of customers to minimize correlations between their loads, thereby expediting the inversion of connectivity information.

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5. Survey of approaches for phases balancing in LV networks

Work presented in [1] uses the neural network in conjunction with a heuristic method which enables different reconfiguration switches to be turned on/off and connected consumers to be switched between different phases to keep the phases balanced. It uses three snapshot of synchronized measurements and demonstrates that the methods can take current measurement data from a network and predict a sub/local optimal switching sequence to balance phase currents. The proposed strategy is to use the neural network to control the switch-closing sequence of each load for the minimum power loss which will lead to the optimal phase balance. The inputs to the neural network are the unbalanced load currents and the outputs are the switch closing sequences for each load.
In [2,3] a new heuristic method (using combinatorial optimization) is compared to a Neural Network to find sub optimal switching sequences. Reference [4] presented performances of a fuzzy logic based controller. The average total phase load is used to measure the success of the state of fuzzy controller by calculating AU/ph (Average Unbalance per Phase). The controller is only designed to invoke when AU/ph drops below 10KW. Results are measured by comparing the initial average power values with that obtained when the fuzzy controller is used.

Pareto-efficient optimisation of LV feeders with Monte-Carlo power flow calculations is proposed in [5] as a method for LV network balancing with a high number of single-phase generators.

References [6,7] introduced an intelligent dynamic residential load transfer scheme for phases balancing. Residential loads can be transferred from one phase to another to minimize the voltage unbalance along the feeder. Each house is supplied through a static transfer switch with three–phase input and single–phase output connection. The main controller, installed at the transformer observes the power consumption in each load and determine which house(s) should be transferred from one phase to another in order to keep the voltage unbalance in the feeder at a minimum.

Assuming existence of a smart metering infrastructure work presented in [8] framed phases balancing as a quadratic assignment problem and suggested the use of ant colony metaheuristic method to solve the optimization problem.

In [9], based on the latent reactive power capability and real power curtailment of single-phase inverters, a new comprehensive PV operational optimization strategy to improve the performance of significantly unbalanced three-phase four-wire low voltage (LV) distribution networks with high residential PV penetrations was proposed. A multiobjective optimal power flow (OPF) problem that can simultaneously improve voltage magnitude and balance profiles, while minimizing network losses and generation costs, is defined and then converted into an aggregated single-objective OPF problem using the weighted-sum method, which can be effectively solved by the global Sequential Quadratic Programming (SQP) approach with multiple starting points.

Reference [10] considered problem of voltage unbalance with specific impact of electrical vehicles and PV panels. Also advanced metering infrastructure is assessed in this respect.

Harmony search algorithm is proposed in [11] as a novel tool for phase swapping in Low Voltage Distribution Networks where the objective is to determine to which phase each load should be connected in order to reduce the unbalance when all phases are added into the neutral conductor.

Work of [12] assessed the additional reinforcement cost (ARC) arising from a 3-phase imbalance, and proposed two novel costing models for main feeders and LV transformers respectively. Each model involves the derivation of an accurate ARC formula based on the degree of three-phase imbalance and a linearized approximation through Taylor's expansion to simplify the detailed ARC formula, enabling quantification of future LV investment in scale.

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6. Survey of approaches for voltage and thermal overload control in active distribution networks

Distribution system voltage and thermal overload controls are realized either as separate control functions or the joint voltage/thermal overload control function. Different control architectures are considered in existing works: centralized, decentralized, distributed, and hierarchical.

A decentralized control scheme was proposed in [1]. The scheme controls customer load in order to manage excessive voltages at periods of high wind generation. The adaptive algorithm is designed to balance the need for power quality (voltage regulation) with the desire to minimize generation curtailment. The adaptation law determines whether the objective function deals with generation curtailment voltage regulation, based on whether the voltage at each node remains close enough to the voltage at the substation. The reactive power is controlled through the inverter on the PV cells. The control signals are determined from local instantaneous measurements of the real and reactive power at each node.

Another decentralized control scheme was introduced in [2]. The voltage control scheme combining the reactive power control and the active power curtailment based on the voltage sensitivity method. The sensitivity analysis utilizes real-time monitoring and calculation of the amount of active and reactive power changes. The required active power to be curtailed and reactive power to be absorbed by the DG unit are estimated using the difference between the target voltage and the measured value. In each period the local state of the network is used to determine the change in voltage magnitude that results from changes in generator reactive or active power outputs.

A two-stage distributed voltage control scheme was proposed in [3]. A local controller on each bus of the network monitors the corresponding voltage. Whenever there is a voltage violation, it uses locally available information to estimate the amount of reactive power that needs to be injected into the bus in order to correct the violation. If the DG units connected to the bus can collectively provide the reactive power estimated by the local controller, they are instructed to do so. Otherwise, the local controller initiates a request for additional reactive power support from other controllers at neighboring buses through a distributed algorithm that relies on "local" exchanges of information among neighboring controllers.

Reference [4] considered model predictive control within a hierarchical control scheme for thermal overloads. Model predictive control lies at the intermediate level of a three-layer hierarchical structure. At the upper level a static optimal power flow computes the required voltage profiles to be transmitted to the model predictive level, while at the lower level local automatic voltage regulators, one for each distributed generator, track the reactive power reference values computed by model predictive control. The proposed method allows to cope with constraints on the voltage profiles and/or on the reactive power flows along the network. If these constraints cannot be satisfied by acting on the available DGs, the algorithm acts on the OLTC transformer.

Work of [5,6], inspired by model predictive control principle, introduced a centralized joint voltage/thermal overload control scheme. This scheme relies on appropriate measurement and communication infrastructures. DGs are categorized as dispatchable and non-dispatchable, respectively, and three contexts of application are presented according to the nature of the DGs and the aforementioned information exchanges. Work of [6] also considered OLTC as control action. At each time step a multi-step optimization problem is solved while the system is modelled using sensitivities computed from power flow model.

A multi-agent distributed voltage control scheme was proposed in [7]. The optimization problem is solved by a moderator agent that minimizes the reactive power support of DG units (agents) subject to voltage constraints, and reactive power limits of the DG units. The multi-agent control scheme is as follows: The agent with the lowest voltage (or highest) requests a voltage change to the moderator and it will run the optimization problem and it assigns the required reactive power change for each DG unit.

In [8] a control scheme that considers capacitors, SVC and LTCs, is proposed. The method assumes that the communication infrastructure is available. The authors model the SVC as a variable reactive power source (positive and negative). The method uses genetic algorithms to minimize the voltage deviations and the network losses, subject to voltage limits and LTC limits.

A novel implementation of optimal power flow was used in [9] for thermal overload control as a centralized control scheme. The authors demonstrate, through simulations conducted on a commercially available substation computer, that such an application of optimal power flow can replace the first-on last-off generator connection agreement, which is the prevailing procedure of network access in the U.K

Reference [10] deals with active network management strategies are short-term policies that control the power injected by generators and/or taken off by loads in order to avoid congestion or voltage issues. The control is a centralized control joint voltage/thermal overloads scheme and considered as a sequential decision problem with explicit account of the uncertainties. The problem is cast as a stochastic mixed-integer nonlinear program, as well as second-order cone and linear counterparts, for which quantitative results are provided using state of the art solvers and a sensitivity analysis was performed over the size of the system, the amount of available flexibility, and the number of scenarios considered in the deterministic equivalent of the stochastic program.

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7. On some legal aspects related to building Global Grid (with specific reference to Europe)

Reference [1] provides some information on subsidies for green energy in EU OCT (Overseas Countries and Territories). It appears every country or territory applies specific scheme and it is reasonable to assume they are actually schemes of the EU state to which country or territory actually belongs. Some other works and documents relevant to this issue include references [2,3]. These references point out that in the context of global grid, the international laws (including those of World Trade Organization (WTO)) play equally important role as regional laws (this include subsidization of renewable energy, see section 3 of reference [2]). A doctoral thesis [4] also considers importance of respecting international laws. It is dedicated to the North Sea Offshore grid, but many suggestions might apply in the context of the Global Grid.
European Investment bank (EIB) also considers possible investments in renewable energy outside Europe and their web-site [5] is to be followed in order to collect some new information that could also be related to subsidies for green energy.

Legislation for putting cables in international waters

Most important document related to this issue is "United Nations Convention on Law of the Sea (UNCLOS)" from 1982 (as extension of previous UN related laws) entry in the force in 1994 [6]. Another related UN document is presented in [7].

Private investors in building a cable in international waters

Most important information are given in references [8,9]. Both references provide some information on the way private investors (or funds) could participate in the investments in electricity sector (including renewable energy). These plans the European Commission coordinates with European Investment Bank (EIB).

NOTE: Reference [10] although dates back to 2006 considered several of above global grid aspects and might prove as useful in further investigations.

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