Replacement of Ancillary Service Resources Lost during Decarbonization

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***Abstract*—Decarbonization increases the need for ancillary services (AnS) but simultaneously decarbonization leads to the loss of power plants providing them. Renewable resources are not primarily designed to provide AnS. The separation of electricity generation from AnS provision is proposed and a concept of a hybrid power plant combining small generators and battery energy storage system (BESS) is introduced in this article. Technologies within such a power plant may be stopped and ready to start when AnS is currently not activated, which saves emissions. Delay in the start of turbines requires BESS support and represents a challenge for turbines scheduling and control/dispatch. The goal of this article is to describe uncertainties associated with the AnS provision and to propose suitable optimization methods and architecture of control algorithms.**

Keywords—decarbonization, ancillary services replacement, scalable modular hybrid power plant, scheduling and control algorithms

I. INTRODUCTION

The Czech Republic and, by extension, the whole EU have irrevocably embarked on the path of decarbonization leading to decommissioning of large power plants (mainly burning fossil fuels). These power plants are unfortunately the major providers of ancillary services (AnS) for grid stabilization, eliminating the negative effects of load volatility.

An increasing number of renewable energy resources (RES) and their P_{inst} may cover a part of the demand on energy but their ability to provide AnS is, by their nature, very limited. Therefore, finding other AnS sources in appropriate volume and quality is necessary.

The contribution is structured as follows: Chapter II provides a brief description of selected AnS which we focus on, chapter III analyzes suitability of different technologies to provide these AnS from different perspectives. A concept of a hybrid power plant providing AnS is introduced in chapter IV. Uncertainties and challenges associated with AnS provision are described in chapter V. Example configuration of hybrid AnS resource is shown in chapter VI, the description of conventional approach to its control is then compared with VPP approach. Basic architecture of scheduling and control algorithms is outlined. Chapter VII provides the description of the technical model of a hybrid power plant and proposes suitable optimization techniques. Conclusions and goals of further research are summarized in chapter VIII.

The benefit of this paper is the presentation of a solution supporting decarbonization by separating power plants covering electricity demand from those providing AnS, and the basic design of the AnS hybrid resource.

II. CONSIDERED ANCILLARY SERVICES

Respecting physical principles of electricity generation, transport and consumption, it is necessary to ensure the balance between power generation and consumption in real time. Transmission System Operator (TSO) is usually responsible for maintaining the balance. TSO procures AnS on transparent markets. The reward for provided service consists of two parts – the payment for reservation (readiness to provide) [€/MW.h] and the payment for regulation energy (RE) physically provided during service activation [€/MWh].

The primary technical goal of AnS is to correct immediately any imbalance between electricity consumption and generation in real time by operational changes of generated/consumed power. When imbalance occurs, the cascade of regulatory interventions through the activation of individual types of AnS is realized to restore the frequency in a defined time (Fig. 1). Considered services are:

- FCR is a local automatic regulation provided by the control system of the power plant (autonomous frequency regulator). The change of delivered power is directly (linearly) dependent on a frequency deviation,
- aFRR is provided by an automatic change of desired unit power output (a set-point) based on a command from TSO load controller; a set-point may be set to any power level within reserved range each second,
- mFRR is provided by changing desired unit power output. The pattern is known (prepare, ramp-up, stay, ramp-down). The activation is realized upon request of the TSO dispatch center. When activated, full reserved power output is delivered.

TSO transparently remunerates provided services based on quality evaluation of time series of delivered power output in second granularity.

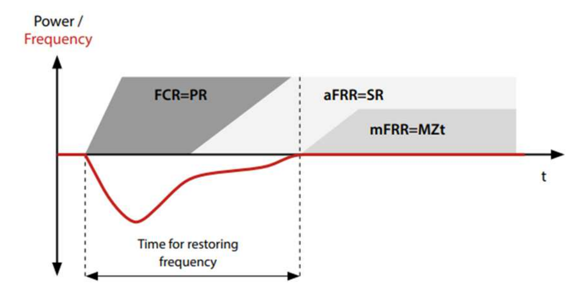


Fig. 1. Sequence of restoring nominal frequency and power balance by ancillary services gradual deployment

III. ANS RESOURCES REPLACEMENT OPTIONS

A. *The Grid Code perspective*

A number of requirements needs to be fulfilled simultaneously when providing AnS – the service has to be:

- measurable to prove that the specified qualitative parameters were met,
- certifiable – there is a set of procedures used to demonstrate the ability to provide services in desired quality,
- fully available within a time interval for which it has been reserved,
- fully available within reserved power output range.

B. *A system operator perspective*

A system operator (usually TSO) seeks AnS that are:

- highly available with no (or limited and predictable) dependency on external factors (season, daytime, temperature, wind flow, solar radiance, heat demand, any other commitments of the service provider to the third parties etc.),
- highly reliable regardless of operational regime of a power plant (power level, state of charge etc.),
- compliant with clearly defined parameters and quality requirements on each service.

C. *Comparison by AnS resource type*

Ancillary service is, by definition, a kind of explicit flexibility which means an ability – either of a single device (consuming, generating or storing electricity) or aggregated set of devices – to precisely change the consumption/generation pattern on command (compared to the expected pattern / baseline).

AnS resource types can be compared (bearing in mind the requirements mentioned above) in several dimensions:

1) individual power plant vs. aggregated units (virtual power plant, demand side aggregated flexibility),
2) generation vs. consumption side,
3) technology with heat delivery vs. one without heat delivery,
4) fuel / technology used,
5) readiness to provide service – technology is running vs. technology is in steady state.

1) Individual vs. aggregated flexibility (geographically concentrated vs. dispersed)

Conventional AnS providers are mostly individual power plants connected to the transmission grid or a very high voltage distribution grid. Power flexibility aggregation on the generation side is perceived only as evolutionary development, e.g., a combination of several CHP units to achieve minimum size of AnS providing unit (1MW) according to the Grid Code.

Power flexibility aggregation (dispersed on demand side) promises replacing lost AnS resources. Although optimization methods are the same, coordinated flexibility utilization from many distributed and geographically dispersed small units is a challenge for control systems architecture and communication technologies.

2) Flexibility on generation vs. consumption side

Conventional providers sit on generation side. Attention is currently drawn to demand side flexibility aggregation. Aggregators face greater uncertainty as available flexibility usually depends on the external parameters, therefore demand side flexibility aggregation may prove to be less reliable. Hence, we expect it to be settled into the AnS market but at the same time it must be backed up by highly reliable technically based providers.

3) With heat delivery vs. without heat delivery

If a power plant also provides heat (any steam cycles, CHP), the coverage of heat demand is a primary goal of such a power plant and electricity then _becomes a by-product. Heat production, therefore, is a limiting factor for AnS provision.

Small generation technologies without heat utilization offer more operational flexibility and therefore they are more suitable for AnS provision.

4) Fuel/technology

Power plants burning fossil fuels (coal and natural gas) represent 60 % of installed power and 60 % of generated energy (Fig. 2) within the fuel mix in the Czech Republic. In contrast, RES represent 21 % of installed power, but they produce only 6 % of energy.

Suitability for the AnS provision can be evaluated respecting pros and cons of each generation technology type:

- fossil power plants (coal-fired ones with steam-driven generators) are mostly used to providing all three types of AnS in the Czech Republic,
- large CCGTs are comparable to steam/fossil ones (a closed cycle gas turbine consists of a steam turbine as well),
- CHPs (combined electricity and heat production) are usually considered to provide mFRR or as a quick starting back-up power plant,

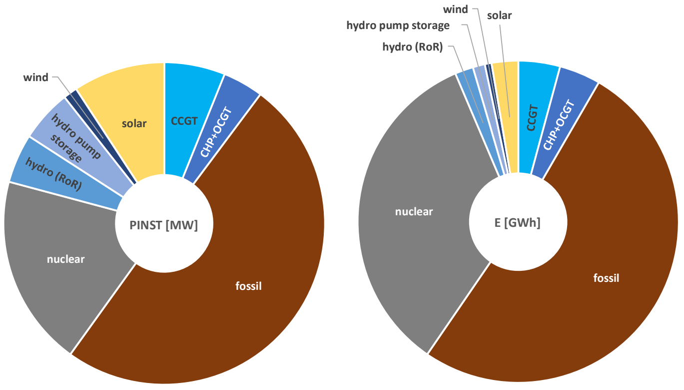
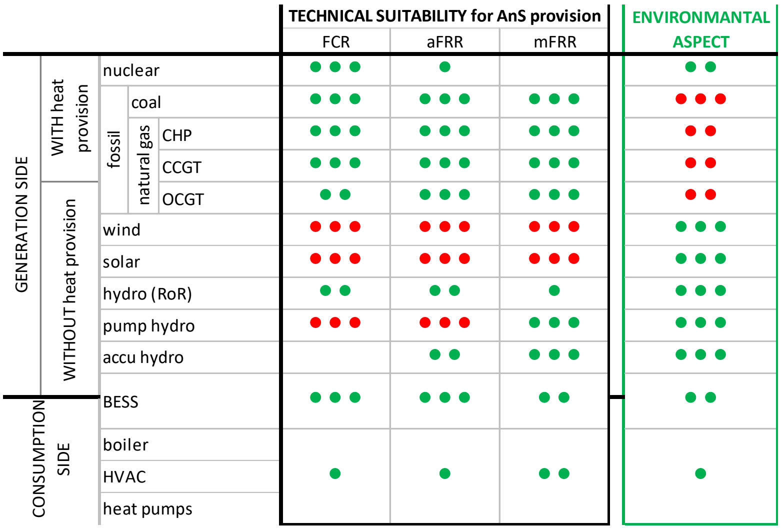


Fig. 2. Structure of generation mix of the Czech Republic (installed power and generated energy



					TECHNICAL SUITABILITY for AnS provision			ENVIRONMANTAL ASPECT
					FCR	aFRR	mFRR	
GENERATION SIDE	WITH heat provision			nuclear	🟢🟢🟢	🟢		🟢🟢
		fossil		coal	🟢🟢🟢	🟢🟢🟢	🟢🟢🟢	🔴🔴🔴
			natural gas	CHP	🟢🟢🟢	🟢🟢🟢	🟢🟢🟢	🔴🔴
				CCGT	🟢🟢🟢	🟢🟢🟢	🟢🟢🟢	🔴🔴
	WITHOUT heat provision			OCGT	🟢🟢	🟢🟢🟢	🟢🟢🟢	🔴🔴
				wind	🔴🔴🔴	🔴🔴🔴	🔴🔴🔴	🟢🟢🟢
				solar	🔴🔴🔴	🔴🔴🔴	🔴🔴🔴	🟢🟢🟢
				hydro (RoR)	🟢🟢	🟢🟢	🟢	🟢🟢🟢
				pump hydro	🔴🔴🔴	🔴🔴🔴	🟢🟢🟢	🟢🟢🟢
				accu hydro		🟢🟢	🟢🟢🟢	🟢🟢🟢
				BESS	🟢🟢🟢	🟢🟢🟢	🟢🟢	🟢🟢
CONSUMPTION SIDE				boiler	🟢	🟢	🟢🟢	🟢
				HVAC				
				heat pumps				

Fig. 3. Comparison of generation technologies from AnS future provision suitability

- nuclear power plants are usually considered to provide only FCR, but technically they can provide a/mFRR as well,
- wind and solar power plants are not technically suitable for AnS provision,
- pump hydro power plants are used mainly for mFRR; they are limited by the capacity of a reservoir; pump hydro power plants are suitable neither for FCR due to its intermittent nature nor for aFRR due to the limited capacity of a reservoir,
- hydro Run of River (RoR) can be used for FCR, a/mFRR may be limited by hydrological conditions,
- hydro accumulation dams are similar but less limited by hydrological conditions,
- OCGTs (open cycle gas turbines) are usually considered to provide mFRR as a quick starting back-up power plant. They might be used for aFRR+ if accompanied by BESS to bridge a start lag.

From a fuel perspective, respecting EU taxonomy:

- power plants burning fossil fuels are the first ones to be decommissioned due to decarbonization,
- natural gas (NG), although it ranks among fossil fuels, is considered as suitable fuel, at least for transition period and small units; commitment of power plants burning NG is currently limited by its availability and its price,
- power plant is considered as green if technology allows burning biogas instead of NG,
- classification of nuclear power plants as RES is the question of a political decision.

Although the current geopolitical situation may affect the short-term perception how the suitability of different types of fuels are taken into account, the declared long term Green Deal objectives do not change.

BESS is technically able to provide any of above mentioned AnS, the only limitation is its capacity (which may be compensated by cooperation with other technologies).

Many technologies on the demand side may be included in flexibility aggregation (boilers, HVAC, heat pumps, etc.) [14, 15]. An electrolyzer is a promising technology for AnS provision on the demand side.

5) Running vs. steady state when AnS is in the reservation

Conventional electricity generating technologies must be running (at least at minimum technical power output) to be able/ready to provide AnS.

Our concept of a hybrid power source helps to reduce emissions (produced while providing AnS) as the technologies within a power plant may be stopped and ready to start if AnS is currently not activated. The idea is built on efficient management of states in which technology may be.

States are defined by their duration and cost characteristics, transitions between states have zero duration. In Fig. 4 a state diagram is illustrated, in which:

- red are states with unlimited time to stay in, they may be left only when a command is issued,
- yellow states are transition ones, their duration is fixed (or defined by stochastic parameters), they cannot be interrupted,
- blue states are transition ones, their duration is fixed, but may be interrupted when a command is issued.

The duration of start and stop sequences of engines challenge operational scheduling and real-time control of engines; it can be partially covered by BESS support (BESS provides required power output until the engine becomes capable to provide power).

IV. THE IDEA OF A HYBRID ANS RESOURCE

The optimistic decarbonization scenario assumes that decommissioned fossil power plants will be replaced by green ones (to cover the demand on electricity) while maintaining the system's ability to provide AnS at unchanged quality. Separating the provision of AnS from electricity generation is crucial to accomplishing this goal.

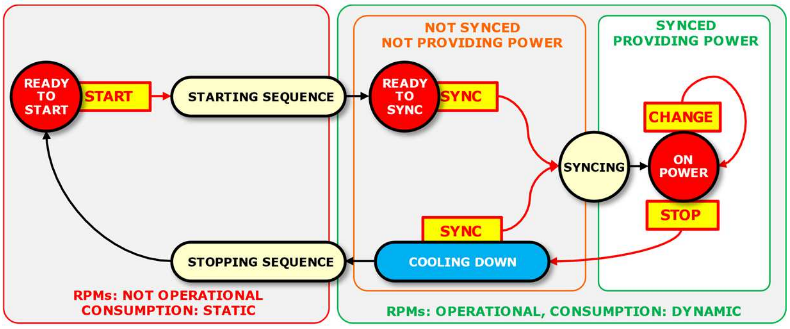


Fig. 4. Example of a state diagram of technology operated in multiple states

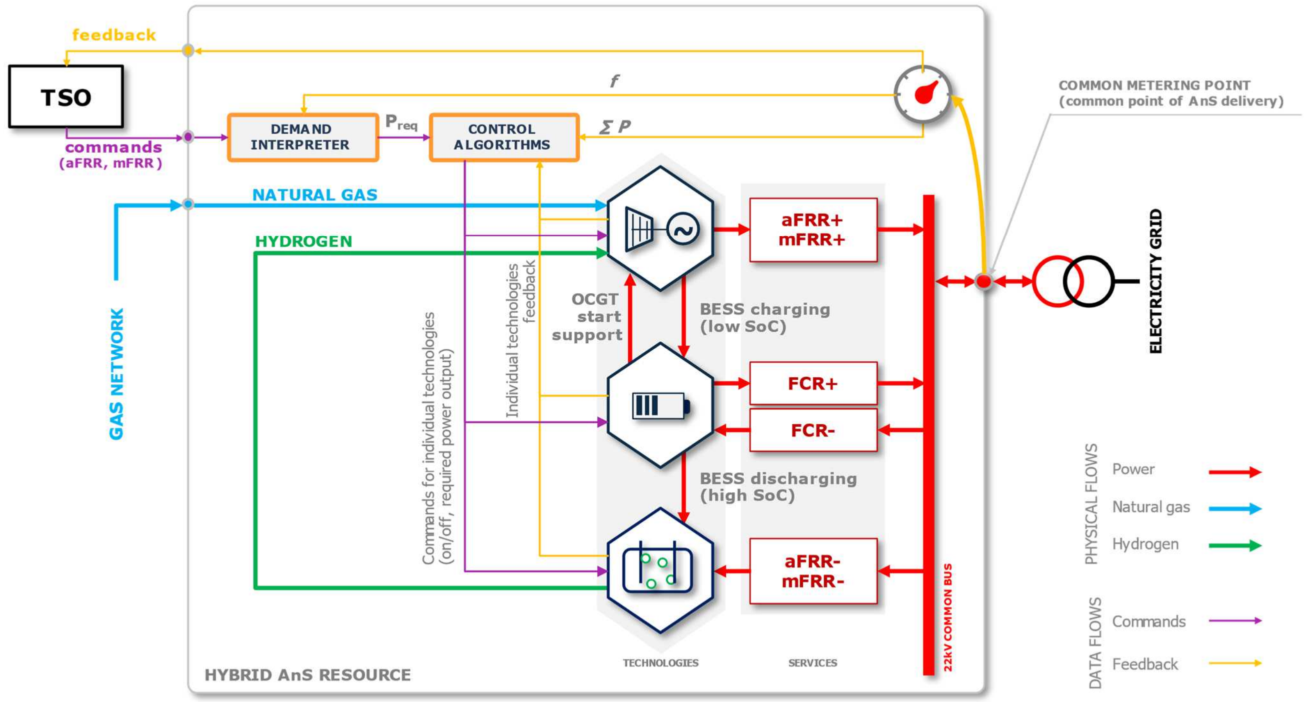


Fig. 5. Scheme of Basic concept of hybrid VPP for AnS provision

Based on the above assumptions, the concept of a stand-alone hybrid AnS source is introduced. Respecting TSO requirements, a combination of BESS, electrolyzer and small OCGTs (Fig. 5) is proposed as the best technical solution. This concept of a hybrid resource consists of a set of multiple types and instances of partial technical flexibilities with known and deterministic characteristics that are integrated to provide a final product.

A hybrid AnS source is a geographically concentrated technical virtual power plant which may be tailored to specific site conditions or needs – it is scalable (by setting proper power and capacities of component), flexible and modular (in a combination of proper components). Its components (partial technologies) might be classified by:

- the degree of continuity of delivered/absorbed power
  - C = technology with power continuously controllable between P_{min} and P_{max} ($P_{min} \leq P \leq P_{max}$) where:
    - zero power level is included in range ($P_{min} \leq 0 \leq P_{max}$), e.g. BESS,
    - zero power level is not included in range ($0 < P_{min} < P_{max}$), e.g. engines (OCGT, CHP, CCGT),
  - D = technology with output power discretely controllable (on/off or in discrete steps) ($P \in \{0, P_1, P_2, \dots, P_{max}\}$),
- the range of states in which the technology can be:
  - S = technology is permanently operated in one state where it is capable to provide/absorb power,
  - M = technology is operated in multiple states, at least the technology:
    - is not capable of providing power but has low operational cost,
    - is capable of providing power but has high operational cost.

Based on preliminary analyses [16], it is recommended to assemble a standalone hybrid AnS source from OCGT, BESS and an electrolyzer as the most flexible solution:

- C/S – BESS (pros: immediate reaction, quick ramp rate, cons: stamina limited by BESS capacity),
- C/M – CHP, OCGT, electrolyzer (a common constraint is a delay in reaching the operational state in which the technology is capable to provide power):
  - OCGT (pros: ready to start without prerequisites, cons: low efficiency, especially on low power output level),
  - CHP (cons: must be pre-heated to be ready to start (causing higher costs), high efficiency in combined cycle, flexibility is limited if heat is provided),
  - electrolyzer (pros: ready to start without prerequisites, limited range and dynamics of power level control).

V. CHALLENGES FOR CONTROL ALGORITHMS

All technologies are mutually connected and deliver their power output to a common 22 kV internal bus. The goal of the control algorithms is to ensure delivery of exact summary power output from a power plant in real-time by precise coordination of all partial technologies, considering their self-consumption (delivering netto output on a single metering point). All three expected AnS (FCR, aFRR, mFRR) may be provided simultaneously. We face following challenges within operational control:

A. *Activation uncertainty*

Once the AnS is sold in a given trading interval, the hybrid AnS source must be able to fulfill operational requirements (TSOs commands) upon a command which:

- may be issued anytime within a given trading interval (activation uncertainty from a time perspective),
- may require any power level from the reserved range (activation uncertainty from a target power level).

Therefore, the worst-case scenario must always be considered within scheduling activation of engines and controlling their power output (to guarantee service parameters/quality).

B. *Nature of quality evaluation criteria (ideal realization of the service is not defined)*

The individual services are defined relatively precisely in the Grid Code. However, an “ideal” course of power output is not defined. Instead of it, there are defined only tolerance bands which are asymmetric and dependent on previous commands (dynamic tolerance tunnel). A tolerance tunnel cannot be built for a future time period as a future command is unknown till it is issued by TSO. The impossibility of setting tolerance bands for the future time period complicates the optimal power output course calculation.

C. *Uncertainty of internal characteristics*

Characteristics of technologies are stochastic but – for simplicity – they are considered deterministic in our basic concept. However, stochastic characteristics will be taken into account in our later research:

- duration of transition states, e.g. starting time, generator synchronization time, etc.; stochastic characteristics are asymmetric, e.g. Weibull,
- control accuracy of technologies (power level and ramp-rate).

The control method also compounds the dependence on the characteristics of the environment, e.g. P_{min} and P_{max} of OCGTs depend on the temperature of the intake air.

VI. COMPARISON OF CONTROL APPROACHES

As an example, let us assume the total power output of a power plant 30 MW allocated to AnS as follows: 10MW FCR, 10MW aFRR+ and 10MW mFRR+.

Based on preliminary simulations [16], minimum sets of technologies were identified for the provision of each service:

- for FCR ±10MW:
  - 10MW/10MWh BESS,
  - 5MW OCGT to charge BESS in case of low state of charge (SoC),
  - 5MW electrolyzer to discharge BESS in case of high SoC,
- for aFRR+10MW:
  - 10MW OCGT,
  - 10MW/5MWh BESS to bridge the OCGT starting sequence,
- for mFRR+10MW:
  - 10MW OCGT,
  - no BESS support is required for mFRR.

The availability of these minimum capacities of partial technologies must be constantly guaranteed for each service.

Two different approaches to power plant control are compared in the following chapters:

A. *Conventional approach (separate control of technology sets dedicated to individual services)*

Technologies are physically dedicated to individual services. There is no coordinated utilization among these particular technology sets, which decreases operational efficiency, therefore increases operational costs. There is also a risk of suboptimal investment as potential synergies in technology sizing are not exploited.

B. *VPP approach (coordinated control of whole power plant)*

Contrary to the conventional approach, technologies are shared between services, which increases operational efficiency. If a particular technology is not utilized by a particular service, its “free” power/capacity may be utilized by another one, e.g. it is possible to share a one turbine power output for two AnS.

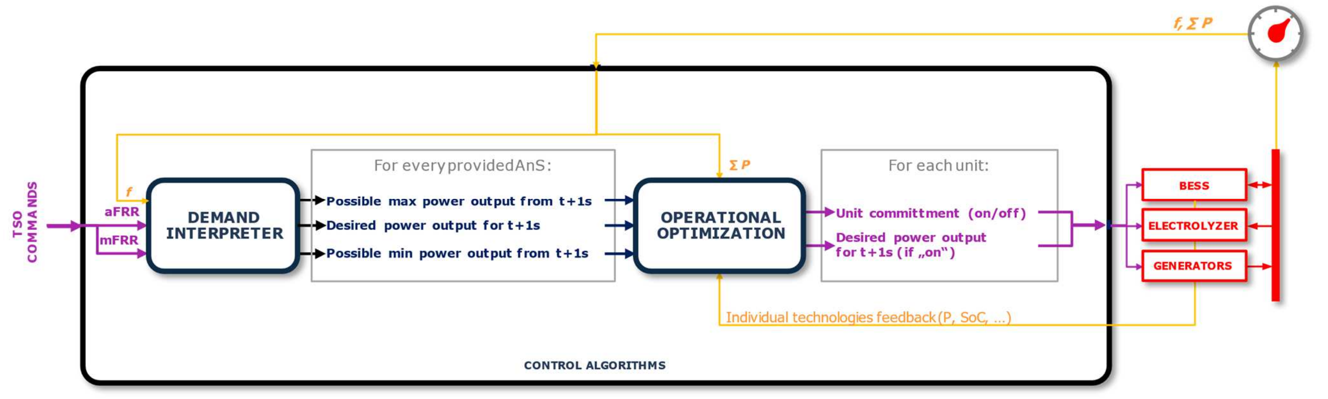


Fig. 6. Basic architecture of control algorithms

VII. EXPECTED ARCHITECTURE OF CONTROL ALGORITHMS

Hybrid AnS resource appears to TSO as a single (virtual) unit with a single meter point. The economical goal of optimization algorithms is to maximize the financial profit from provided AnS (revenue from provided RE - operational costs). The technical goal is to ensure the delivery of total power output corresponding to the sum of ideal power outputs of individual services, respecting technical limits of individual technologies.

It is expected that a robust optimization will be able to find the best solution. Alternatively, a complex task can be split into separate (independent) ones, which might be suboptimal, but probably easier to realize in real-time. It is proposed to use following separate modules (Fig. 6) – a demand interpreter and an optimizer.

1) Demand interpreter

The goal of a demand interpreter is to translate TSOs commands for individual AnS into the required total course of power output. The translation is based on:

- service definition including service quality evaluation criteria,
- current TSO commands for services,
- history of service demand/delivery.

Outputs from a demand interpreter module are (for each service) three time series of:

- desired power output course for optimization horizon,
- prospective min and max power output courses for optimization horizon.

The optimization horizon starts at the current time and its minimum length is two trading intervals (2 x 15 minutes). Desired power output and min/max power outputs are calculated from AnS commands at actual time and the assumption that there will come no new AnS commands during the optimization horizon.

The relevant time series are summed up and passed to the optimization module as total desired power output (including self-consumption), total prospective min and total prospective max power outputs.

2) Optimizer

The primary goal of this module is to provide the required power output and simultaneously to minimize total operational costs concerning both cost and technical characteristics of individual technologies.

From a Grid Code perspective, relevant technologies must be operated (kept steady or on desired power output) in such a way as to comply with total actual demand on AnS and total prospective max/min demand on AnS.

From a technical perspective, the goal is to optimally schedule the run of each technology unit (OCGT, BESS module, electrolyzer) and set their power levels.

Secondary goals are:

- to maintain BESS operational parameters, mainly optimal SoC range by utilizing other technologies to charge/discharge BESS,
- ensure equal wear of each unit by altering them in activation.

It is currently under investigation, if the optimization task can be split into two separate ones:

- unit scheduling,
- balancing of total power output among technologies (OCGTs are synchronized with the grid (in "synced" state), BESS and electrolyzer).

VIII. TECHNICAL MODEL

The technical model of the system consisting of several OCGTs, a BESS module and an electrolyzer can be described in terms of constraints. For simplicity, the constraints described here do not include the special form of constraints at the beginning and the end of the optimization horizon. Indexes, constants and variables are explained in Table I.

Constraints of the OCGT technical model:

- OCGT power and ramp rate limits in synced state
  - Power limits:
    $$P_{i,t}^{OCGT} = 0 \text{ or } P_{min}^{OCGT} \leq P_{i,t}^{OCGT} \leq P_{max}^{OCGT}$$
  - Ramp rate limits:
    $$\left|P_{i,t}^{OCGT} - P_{i,t-1}^{OCGT}\right| \leq R_{0,max}$$
  - Ramp rate change limits:
    $$\left|P_{i,t}^{OCGT} - 2 \cdot P_{i,t-1}^{OCGT} - P_{i,t-2}^{OCGT}\right| \leq R_{1,max}$$
- OCGT power and ramp rate limit in not synced state:
  $$P_{i,t}^{OCGT} = 0$$
- Self-consumption – a function of power P and state s (synced or not synced)
  - constant in not synced states
  - linear function of P in synced state:
    $$P_{SC,i,t}^{OCGT} = f_{SC}\left(P_{i,t}^{OCGT}, s_{i,t}\right)$$

Constraints of the BESS technical model:

- BESS power limits:
  $$0 \leq P_{ch,t}^{BESS} \leq P_{max}^{BESS}$$
  $$0 \leq P_{dis,t}^{BESS} \leq P_{max}^{BESS}$$
- BESS energy limits:
  $$E_{min}^{BESS} \leq E_{t}^{BESS} \leq E_{max}^{BESS}$$
- BESS energy balance:

$$E_{t}^{BESS} = E_{t-1}^{BESS} + K_{P2E} \cdot \eta_{ch} \cdot P_{ch,t}^{BESS} - K_{P2E} \cdot \frac{P_{dis,t}^{BESS}}{1 - \eta_{dis}}$$

where K_{P2E} is the conversion constant between actual power and energy (constant value depends on time granularity). In case of one second time granularity the constant value equals 1/3600 h.

The electrolyzer is used just for discharging the BESS in case of energy surplus. This may happen in case of negative AnS activation or positive AnS deactivation. Discharging electrolyzer power must conform this constraint:

$$P_{i,t}^{ehl} = 0 \text{ or } P_{min}^{ehl} \leq P_{i,t}^{ehl} \leq P_{max}^{ehl}$$

Overall system power balance constraint is:

$$\sum_{i}\left(P_{SC,i,t}^{OCGT} - P_{SC,i,t}^{OCGT}\right) + P_{dis,t}^{BESS} - P_{ch,t}^{BESS} - P_{i,t}^{ehl} + P_{t}^{emer}$$
$$= P_{req,t} + P_{t}^{dump}$$

There might be additional hard constraints for emergency and dump power which represent AnS tolerances:

$$P_t^{emer} \leq P_{max}^{emer}$$
$$P_t^{dump} \leq P_{max}^{dump}$$

The optimization goal is to minimize all costs necessary for P_{req} delivery. The objective function includes the following components:

- OCGT operation costs in both synced and not synced states:
    - synced states: linear costs as a function of power (EUR/MW)
    - not synced states: constant costs (EUR/hour)
- OCGT costs of transition between states (EUR/transition)
- a penalty for power deficit and surplus (EUR/MW)

Optimization with a known profile of required value (or good profile estimation/prediction) leads to MILP task (Mixed Integer Linear Programming). The minimum length of the optimization horizon is two trading intervals (2x15 minutes). An acceptable MILP solution must guarantee that the system will be able to reach any new requested value within the range of sold AnS, which may come from TSO during the optimization horizon. This problem will be the subject of further research.

IX. CONCLUSION

Resources of AnS using fossil fuels will be lost during decarbonization. The optimistic decarbonization scenario assumes that decommissioned fossil power plants will be replaced by green ones to cover demand on electricity. Unfortunately, such scenario does not promise equivalent availability of AnS. Separating provision of AnS from electricity generation is proposed as an important decision helping to accomplish decarbonization goal.

TABLE I. INDEXES, CONSTANTS AND VARIABLES USED IN THE HYBRID ANS RESOURCE TECHNICAL MODEL DESCRIPTION

Symbol	Unit	Description
i	-	OCGT index
t	-	time index
P_{min}^{OCGT} P_{max}^{OCGT}	MW	min/max OCGT power output
$P_{i,t}^{OCGT}$	MW	current OCGT power output for i-th turbine and time t (variable)
$R_{0,max}$	MW/s	maximum OCGT ramp rate
$R_{1,max}$	MW/s	maximum OCGT ramp rate change
$P_{SC,i,t}^{OCGT}$	MW	current OCGT self-consumption (variable)
f_{SC}	MW	OCGT self-consumption function
$s_{i,t}$	–	OCGT state; not synced, synced (variable)
P_{min}^{BESS} P_{max}^{BESS}	MW	max BESS power output for both charging and discharging
P_t^{BESS}	MW	current BESS power output (variable)
E_{min}^{BESS} E_{max}^{BESS}	MWh	min/max BESS energy level
E_t^{BESS}	MWh	current BESS energy level (variable)
K_{P2E}	h	conversion constant between actual power and energy
η_{ch} η_{dis}	%	charging/discharging BESS efficiency
P_{min}^{ehl} P_{max}^{ehl}	MW	min/max electrolyzer power
$P_{i,t}^{ehl}$	MW	current electrolyzer power (variable)
$P_{req,t}$	MW	current desired power value which corresponds to actual AnS activation
P_t^{emer}	MW	current power deficit (variable)
P_t^{dump}	MW	current power surplus (variable)
P_{max}^{emer}	MW	max emergency power
P_{max}^{dump}	MW	max dump power

A concept of a scalable modular hybrid resource of AnS combining OCGT, BESS and hydrolyzer was introduced. The concept is based on coordinated collaboration of particular technologies in the VPP frame. Contrary to the conventional approach (each AnS has a physically dedicated set of technologies), it brings synergy especially in operational costs savings and higher reliability. However, we must cope with many challenges and uncertainties (lack of definition of ideal course, activation uncertainty and operational/technical uncertainty) when controlling.

Optimization with a known future course of required power output (or good profile estimation/prediction) leads to a MILP task where an integer character of the task is determined by the state characteristics and discontinuous power output range of OCGT.

The robust optimization algorithm will be developed during the further research for real implementation. This algorithm ensures the meeting of TSOs requirements even in the situation that future course of service required power is unknown.

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