AUTOMATIC POWER REDUCTION CONCEPT FOR RENEWABLE GENERATION SITES

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Due to the growing number of renewable generation power plants installed within worldwide power systems both at the level of distribution and transmission networks, grid operation is becoming more and more challenging. Under this context, critical situations with violations of operational restrictions are occurring more and more frequently. To avoid such instances, an automatic power reduction logic could be implemented at the RES (Renewable Energy Sources) generation units level under specific conditions of the network such as N-1 conditions.

This paper presents an automatic power reduction concept possible to be considered for renewable power generation power plants based on PTDF (Power Transfer Distribution Factors) computation using SmartFlow/Eurostag™ software and a dedicated SCADA (Supervisory control and data acquisition) system to be correlated with the energy management system of the generation site in order to achieve an optimized active power control of the generated power.

Keywords: Automatic power reduction, congestion management, SCADA

1. Introduction

The ongoing integration of renewable energy resources such as Photovoltaic Power Plants (PVPP), Wind Power Plants (WPP), Electric Vehicle (EV), and Heat Pumps (HP) represent a big challenge for the grid planners and operators both at the distribution and transmission level. Congestion problems in transmission and distribution networks are related to both network elements overloadings (overhead lines, and power transformers) and voltage problems (voltages being close to the threshold values) [1-2].

Grid expansion is not necessarily the best and most cost-effective approach to integrate more renewable energy outputs complying as well with the safety conditions of the grid under peak generation time intervals. Because grid operators are responsible for monitoring the security of the system, they must take corrective steps more often to avoid violations of maximum loading and voltage limitations of grid elements, particularly for lines and transformers. One conceivable option is to restrict the total energy produced by renewables under specific peak generation

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conditions, limited in time. Several methods of implementing congestion management measures for a secure grid operation have been reported in the literature, including switching actions for optimized grid topology, the use of power flow controlling devices (TCSC – Thyristor Controlled Series Compensation, SSSC – Static Synchronous Series Compensator, SmartValves, Phase Shifter Transformers) and the usage of the energy producers/consumers flexibility in the favor of safe grid operation [3-5].

At the level of the Romanian National Power System for which we have performed the preliminary RES automatic power reduction concept definition, the Regulatory Authority (ANRE) have included within a dedicated order the conditions under a new generation site may opt for an operational power limitation for complying with the network safety condition under N-1 configuration [6].

This paper focuses on renewable power generation curtailment by using automatic power generation reduction as a congestion management measure. It is shown that power transfer distribution factors (PTDFs) based on the full non-linear load flow equations deliver the best approximation of changes in the grid state since they are mathematically the most appropriate representation of the physical power flows [7].

The paper is structured as follows: **Section 2** presents the main power limitation techniques used in modern power systems; **Section 3** presents the working principle recommended for the automatic power reduction logic and **Section 4** presents the automatic and protection devices necessary for the implementation of the automatic.

2. Power limitation techniques

Hereunder several examples of power limitation techniques that can be used to limit the output of renewable energy sources are listed as per existing literature on the matter [8-10]:

- **Curtailment:** This method entails physically restricting the production of a renewable energy source, such as shutting down or lowering the power of a wind turbine or solar panel. Curtailment is a power limitation technique that includes physically restricting the output of a renewable energy source, such as shutting off or lowering the output of a wind turbine or solar panel. Curtailment is frequently employed as a last option to maintain the electrical grid's stability and dependability [11,12].

There are several ways in which curtailment can be implemented, including:

- **Generation control**: *Automatic curtailment:* When the grid is nearing capacity, this strategy employs automated control systems to lower the output of the renewable energy source; *Manual curtailment*: When necessary, this strategy entails manually lowering the output of the renewable energy source; *Scheduled curtailment*: This strategy entails lowering the output of the renewable energy source at predefined times, such as when demand is low or there is an extra generation within the grid is predicted [13-15].

- **Energy storage systems**: This method uses battery storage systems (BESS) or pumped storage hydro powerplants (PSH) to store extra power provided by a renewable energy source. When a renewable energy source produces more power than is required, the extra energy may be stored in a battery or in the water reservoir of the PSH and used later when demand is higher. This smooths out the output of the renewable energy source and reduces the possibility of grid overloads [16-18].
- **Demand response:** represents a strategy which enables adjusting of electricity consumption in response to the supply. This technique encourages the users, which can be household or industrial consumers to change their energy usage by reducing or shifting their electricity usage during peak hours in response to time-based pricing or other types of financial rewards, thus balancing the grid better matching the demand for power with the energy supply [19,20].

3. OPERATIONAL LOGICS

Two distinct modes of operation are suggested for the automatic power generation reduction to be considered at the level of a new renewable generation site which cannot be integrated within the grid under safe N-1 conditions without grid reinforcements necessary to be implemented by the grid operator:

- **Mode 1** – Contingencies & Sensitive Elements;
- **Mode 2** – Contingencies list.

- **Mode 1** – Monitoring dangerous Contingencies & Sensitive Elements list for PVPP/WPP power generation reduction;

The key sensible network elements (resulting after N-1 preliminary analysis) are suggested to be monitored during real operation (they are marked on the diagram with P_{ES1}, P_{ES2}...P_{ESn}).

When the imposed power limit is exceeded on one of the sensitive elements (power limit threshold denoted by P_{TR1}, P_{TR2}...P_{TRn}) it is checked if this is caused by the associated dangerous contingency (denoted by C_1, C_2...C_n).

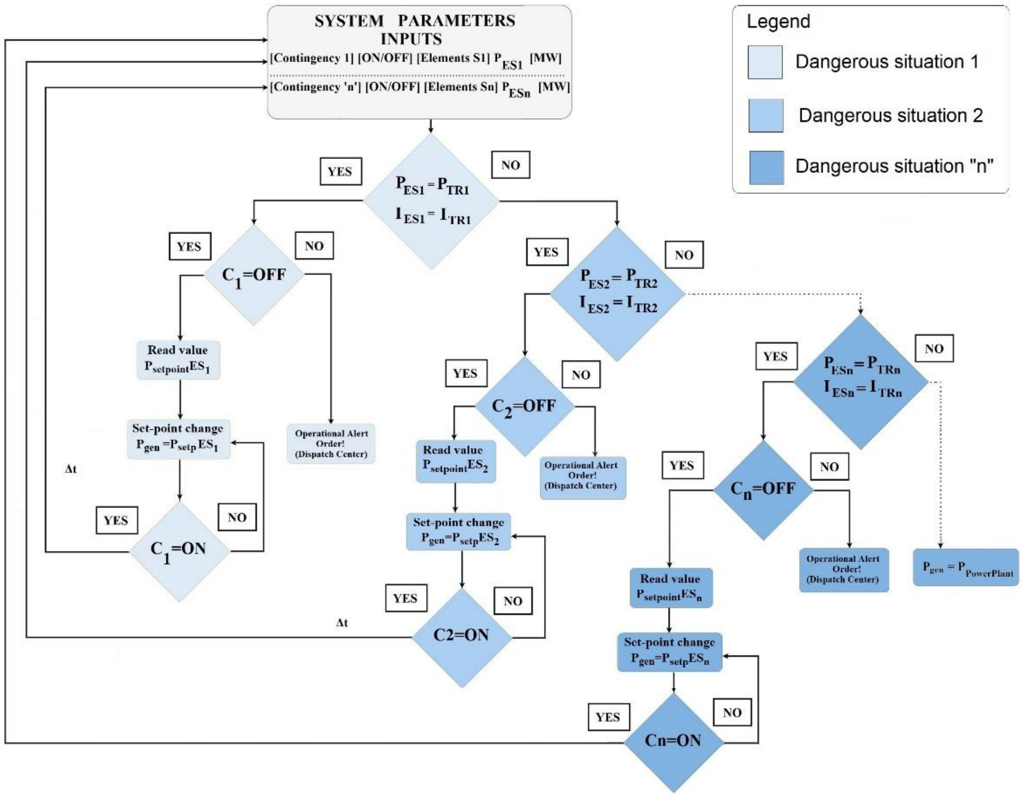

Fig. 3.1 - Automatic power limitation – Mode 1 ON logic diagram

When both conditions are met: reaching the power limit on the key sensitive network element (P_{ESn}=P_{TRn}) and the occurrence of the associated contingency (C_n=OFF), then the active power setpoint value assigned to the sensitive element ("Read value $P_{setpointESn}$") is read, and the power generated by the powerplant will be set to this setpoint value ("Set – Point change P_{gen}=$P_{setpESn}$") as a result of the activation of the setpoint power. If the condition of occurrence of the contingency associated with the key sensitive network element is not met (C_n=ON) then a signal of "Operational Alert Order!" is sent to the Dispatch Center of the TSO (Transmission and System Operator).

If the condition of reaching the threshold power limit (P_{ESk}=P_{TRk}) is not fulfilled for sensitive element “k”, then it will proceed to check the condition for the sensitive element "k+1" (P_{ESk+1}=P_{TRk+1}), and the process will be repeated until reaching the maximum number of dangerous situations "n". Thus, the automatic power reduction activation logic scheme, Fig. 3.1., will involve a loop check of those previously described by reading the system quantities at a Δt interval (4-5 s).

An additional deactivation logic diagram, shown in Fig. 3.2., is required for deactivating the logic after the recorded overloading is not present anymore.

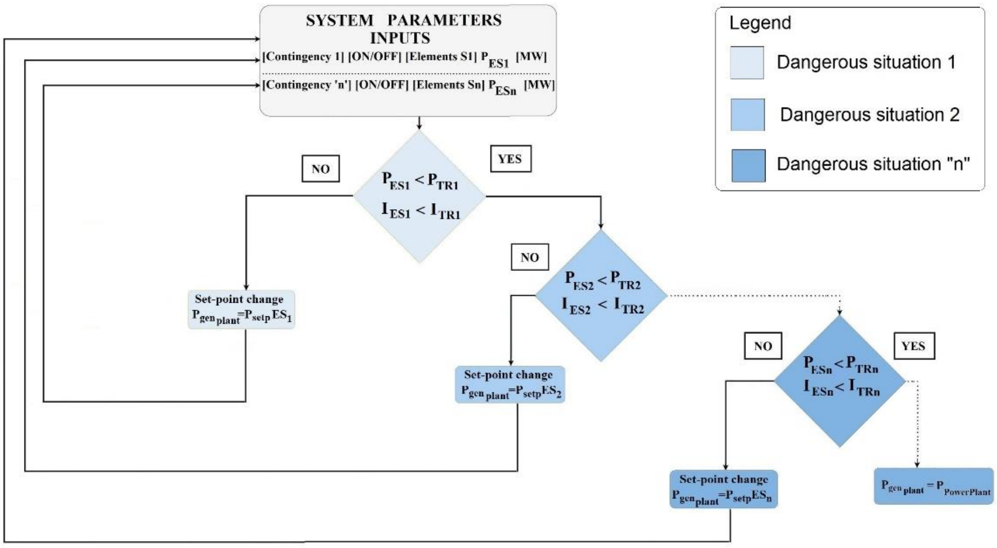

Fig. 3.2 – Automatic power limitation – Mode 1 OFF logic diagram

- **Mode 2** – Monitoring dangerous Contingencies list for PVPP/WPP disconnection.

The dangerous contingencies that must be monitored during real-time operation are denoted: C_1, C_2...C_n. When a contingency occurs on a monitored line (C_k=OFF), the power generated by the power plant under analysis will be set to 0 ($P_{gen}=P_{setpESk}=0$). The power plant will be disconnected using one of the following approaches:

• Activation of automation at the power plant level at the time of initiation of the trip signal received from the protection of the monitored Overhead Line (OHL), as one of the dangerous contingencies from the C_1,C_2,...C_n list, **before the actual tripping of the monitored OHL**, or:

• Activation of automation at the power plant level after the initiation of the trip signal received from the protection of the monitored OHL (as one of the dangerous contingencies), and **after the actual tripping of the monitored OHL**.

In Mode 2 operation, the automation will receive the protection signal for tripping and/or breaker position, and the associated information will be retrieved from both ends of the monitored OHL (from the contingency list). Mode 2 operation will allow addressing various dangerous situations during grid operation (different energy mix, the specific configuration of the network, variation of the load curve in real time in the analysis area, etc.).

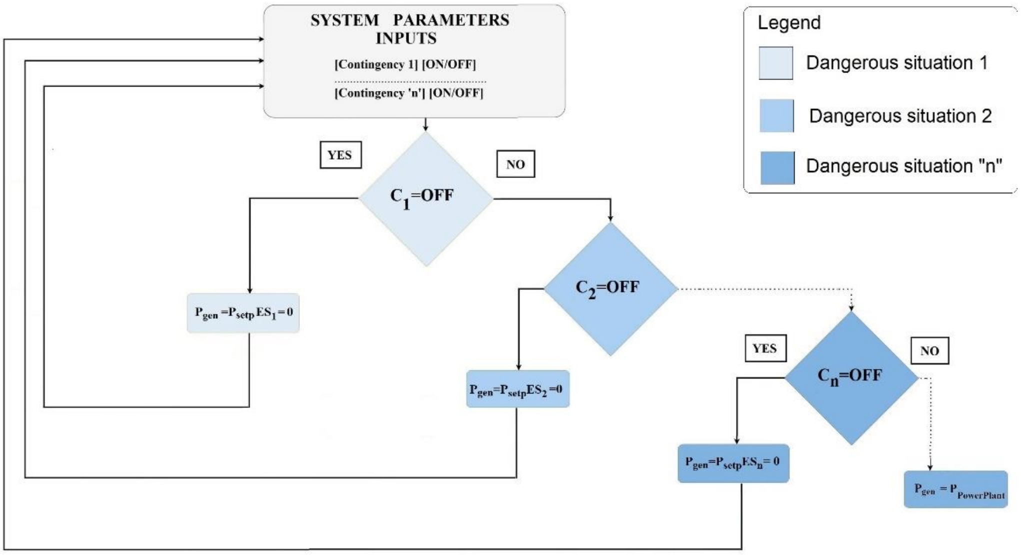

Fig. 3.3 - Automatic power limitation - Mode 2 ON logic diagram

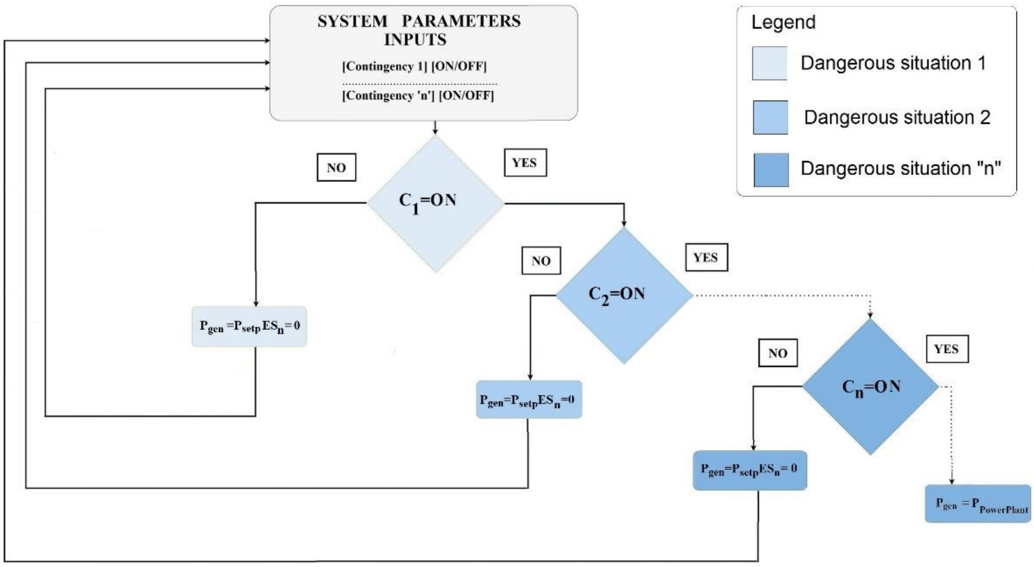

Fig. 3.4 - Automatic power limitation - Mode 2 OFF logic diagram

4. Recommended system architecture

The automatic power limitation is recommended to be carried out with the help of an application installed in the SCADA system of the power plant. The architecture of the containment system is shown as a preliminary concept in Fig. 4.1 [21-24].

From a hardware point of view, the SCADA system of the plant, in which the automatic power limiter will be installed, is mainly composed of the following components:

• SCADA server; Routers / Switches; UPS (Uninterruptible Power Supply); Industrial rack; RTU (Remote Terminal Unit); Media converter; Measuring equipment; PCs (HMI).

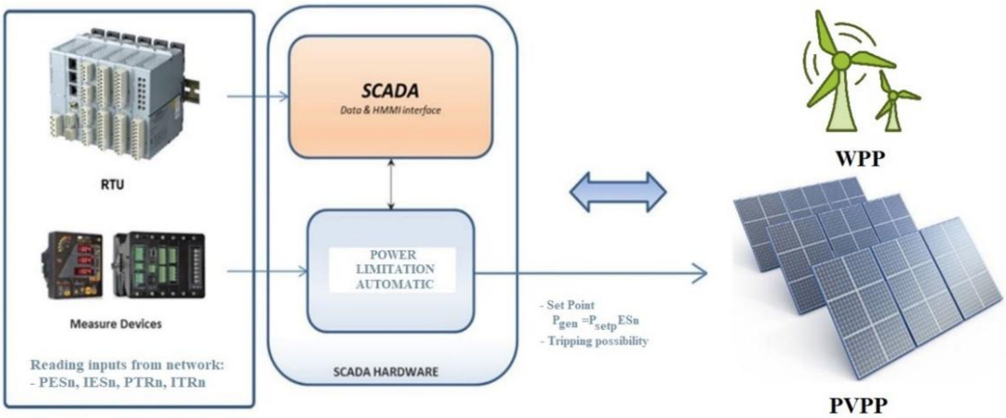

Fig. 4.1 – Architecture of an automatic power limitation system

The dedicated SCADA system to be implemented at the level of a power generation site will communicate with the equipment necessary to be considered within the electrical substations of each monitored dangerous contingency and sensitive element via a dedicated optical fiber communication channel or a dedicated GSM communication channel. The communication system is necessary to be designed in a redundant manner regardless of the selected communication system.

The power plant's internal communication infrastructure will be based on a LAN (Local Area Network) type system. The automation information will thus be available both to the operators in the control room of the plant and to any remote control point. To achieve the most accurate power regulation, power measurement (feedback loop) is necessary. The system will include current transformers, voltage transformers, and measuring equipment that transmit data to the automation application [25-27].

5. Case study – input data and assumptions

Selected test network consists of one main analyzed area, nominated Zone 1, the network diagram is shown in Fig. 5.1.

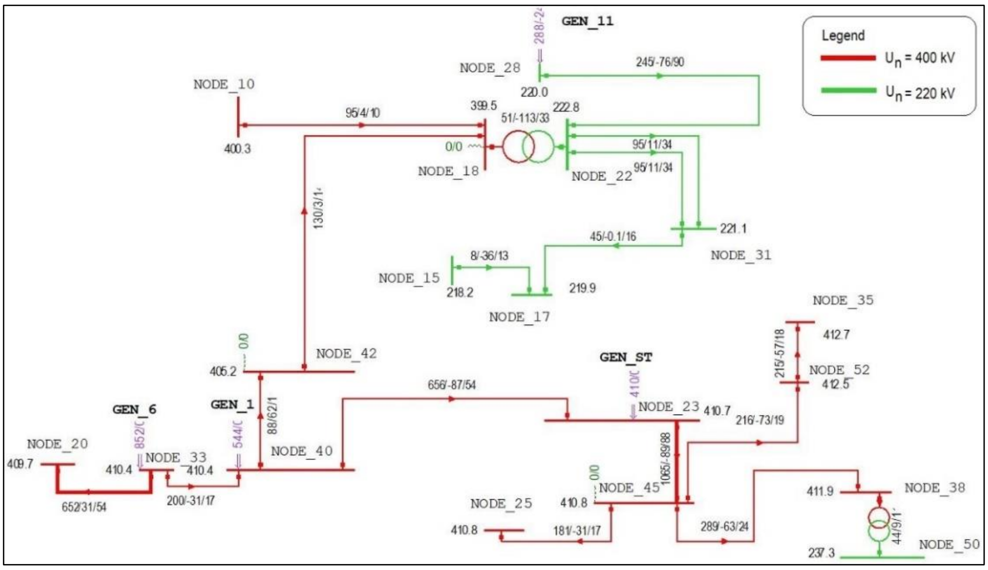

Fig. 5.1 – Analyzed network diagram – Zone 1

• Network topology data

The number of nodes on the different voltage levels and number of power transformers are presented in Table 1 and Table 2.

Table 1

Network Node Data

Zone 1/Un [kV]	**<33 kV**	**110 kV**	**220 kV**	**400 kV**	**TOTAL**
Quantity [-]	13	86	6	9	**114**

Table 2

Transformer Data

Zone 1/Un [kV]	**TF 110/MV**	**AT 220/110 kV**	**AT 400/220 kV**	**TF 400/110 kV**	**TOTAL**
Quantity [-]	11	5	2	6	**24**

The total number of overhead power lines in the analysis areas can be found in Table 3:

Table 3

OHL Data

Zone/Un [kV]	**OHL 110 kV**	**OHL 220 kV**	**OHL 400 kV**	**TOTAL**
Zone 1	115	7	15	**137**

• Data inputs for power demand and power generation is shown in Table 5 and Table 6.

Table 5

Power Demand Data

Demand	Zone 1	
	P_c [MW]	Q_c [MW]
TOTAL	1056.5	262.4

Table 6

Power generation Data

Generation Unit Type	Zone 1	
	P_n [MW]	P_g [MW]
Renewables (Photovoltaic and Wind Power Plants)	3420.5	2606
Others (Classical Power Plants)	260.1	212.8
TOTAL	**3680.6**	**2818.8**

6. Case study – Results

• N-1 criterion simulation

During the N-1 the following critical situations, with the renewable generation unit GEN_ST in operation was recorded, see Table 7. The results highlighted that the total number of sensitive elements required to be monitored by the automatic limitation system is two 400 kV OHLs (OHL 400 kV NODE_45 - NODE_23 - 1 and OHL 400 kV NODE_20 - NODE_33 – 1):

Table 7

No.	Dangerous Contingency C1, C2	Sensitive Element ES1, ES2	S_{max}	S_N	S_{N-1}	S_{N-1}/ S_{max}	I_{N-1}/ $I_{lim.term.}$
			[MVA]			[%]	
1	OHL 400 kV NODE_20-NODE_33-1	OHL 400 kV NODE _45 -NODE_23-1	1184.1	862.6	1378.9	133.8	131.2
2	OHL 400 kV NODE _45 -NODE_23-1	OHL 400 kV NODE_20-NODE_33-1	1184.1	657.9	1260.4	118.1	119.5

The threshold power (P_{TR}) and the active power flowing through the sensitive elements during N-1 situation (P_{ES}), the possible power generation at the level of the analyzed power plant for avoiding over-loadings (P_g PVPP) as well as the power reduction needed for avoiding the overloading (ΔP) are shown in Table 8.

Table 8

No.	Dangerous Contingency C1, C2	Sensitive Element ES1, ES2	P_{TR1} P_{TR2}	P_{ES1} P_{ES2}	ΔP	$P_{max. GEN\_M}$	
			[MW]			[MW]	[%]
1	OHL 400 kV NODE_20-NODE_33-1	OHL 400 kV NODE _45 -NODE_23-1	1012.4	1378.9	366	0	0
2	OHL 400 kV NODE _45 -NODE_23-1	OHL 400 kV NODE_20-NODE_33-1	1012.4	1260.4	248	79	19

• PTDF Factor Computation

The setpoint power associated with each contingency is computed based on PTDF computation methodology. [28]

Power Transfer Distribution Factors (PTDFs) are used in power systems to determine the amount of power that can be transferred between different parts of the system. They are used to help ensure that the power system remains stable and reliable and that the transmission capacity of the system is not exceeded.

PTDFs are calculated based on the topology of the power system and the characteristics of the transmission lines, transformers, and other equipment in the system. They take into account the voltage levels and power flows in the system, as well as the resistance and reactance of the transmission lines. In the analyzed Case Study the PTDF module available in SmartFlow/Eurostag was used.

For the most critical key sensitive network elements OHL 400 kV NODE_45 -NODE_23 - 1 and OHL 400 kV NODE_20 - NODE_33 - 1 the PTDF associated reduction power factors are available in Table 9.

Table 9

GEN	Voltage Level	Pg [MW]	OHL 400 kV NODE_45 - NODE_23 - 1		OHL 400 kV NODE_20-NODE_33 - 1	
			Reduction coefficient [-]	Active Power Reduction [MW]	Reduction coefficient [-]	Active Power Reduction [MW]
GEN_M	**400 kV**	**410**	**0.785**	**322**	**0.749**	**307**
GEN_6	400 kV	852	0.752	641	0.771	656.7
GEN_1	400 kV	544	0.755	410.5	0.75	407.9
GEN_11	400 kV	234.2	0.264	61.9	0.321	75.1
GEN_5	110 kV	85.6	0.375	32.1	0.424	36.3
GEN_7	110 kV	69.2	0.459	31.8	0.489	33.9
GEN_8	110 kV	64	0.342	21.9	0.396	25.3
GEN_4	110 kV	51.7	0.368	19	0.419	21.6
GEN_2	400 kV	54	0.264	14.3	0.321	17.3
GEN_10	110 kV	30	0.461	13.8	0.492	14.8

GEN	Voltage Level	Pg [MW]	OHL 400 kV NODE_45 - NODE_23 - 1		OHL 400 kV NODE_20-NODE_33 - 1	
			Reduction coefficient [-]	Active Power Reduction [MW]	Reduction coefficient [-]	Active Power Reduction [MW]
GEN_3	110 kV	36.5	0.369	13.5	0.417	15.2
GEN_9	110 kV	39	0.269	10.5	0.327	12.8

To avoid the overloading of each key sensitive network element, the reduction factors and the associated power setpoint shown in Table 9 need to be adopted. For example, in order to solve the overloadings for OHL 400 kV NODE _45 -NODE_23-1, a total of 367 MW need to be reduced from the line power flow, in order to do this, by using the information from Table 9, several approaches/combinations can be deployed: for example one approach is consisting in turning off completely GEN_M, GEN_7 and GEN_3 resulting in a total power reduction of 367.3 MW of the power flow on the line, another approach is consisting in reducing the power generation of GEN_6 until the overloading of the monitored OHL is eliminated (reducing the generated power from 852 MW down to 365 MW).

7. Conclusions

This paper presents an automatic power reduction concept possible to be considered for renewable power generation power plants based on PTDF (Power Transfer Distribution Factors) methodology.

The main power limitation techniques, like voltage control, reactive power control, power factor correction, battery storage, and curtailment (also known as power reduction) are presented in Section II.

In Section III two modes of operation are indicated for an automatic power reduction, and the logic diagrams are presented with a detailed explanation of the suggested working principle – (Fig. 3.1 - Fig. 3.4).

Section IV presents a preliminary approach for entire system architecture for the automatic power reduction concept in order to facilitate the implementation within a real power system.

In order to show the PTDF factor computation, which is the basis of the Automatic Power Reduction logic, a test network is used for creating a case study. The recommended automatic power reduction concept was tested on a dedicated case study in order to validate the suggested methodology of PTDF computation proposed by the paper to achieve under optimum condition two key aspects:

- Safe operation of a power system under N-1 conditions AND
- Minimum power reduction necessary to be applied to a specific power generation site in order to comply with the available grid capacity.

In section V, the main information related to performed case study is included presenting the number of nodes, OHLs, TFOs and demand and generation data. The analyzed case study focuses on an area that experiences a high level of renewable energy penetration, with over 92% of total power generation coming from renewable sources. This substantial reliance on renewables can result in network congestion issues.

In Section VI, the results of the case study (performed using SmartFlow/Eurostag software platform) are shown. Within analyzed area two distinct dangerous situations were identified as contingency risks and associated sensitive elements. These were proved as possible to be avoided by specific power reduction applied to the monitored generation site.

The proposed solution discussed in the paper should be regarded as a temporary measure to ensure the safe operation of a power system until specific grid reinforcements are implemented. These reinforcements will enable the deactivation of the automatic power limitation mechanism.

Within any modern power system associated to the need of increasing the power generation contribution from renewable sources the implementation of the automatic power reduction concepts will be of most importance in complying with the network operation security criteria, allowing time for grid operators to implement the necessary strengthening works for safe network operation on long term.

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