

# Integration of Solar Parks: Global Impact of Intermittent RE Generation

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**Abstract:** - This research paper intends to cover the integration of intermittent renewable energies in an existing electrical system and in particular in the case of solar parks. This includes aspects related to the operation, control and security analysis of solar parks in the transmission system. The delivery of power from Solar Parks to the transmission system is related to the security of the electrical system. The main aspect to consider is the integration of Solar Parks and how regulates them with the global problem in which the energy balance of the transmission system to be maintained and the consequences when this balance is lost voltage and flows control also comparative analyze in this work.

**Key Words:** Security Analysis, Integration of Intermittent Renewable Energy (RE) Generation, Solar Park, National Solar Mission.

## I. INTRODUCTION

The electricity transmission system receives the energy produced by all generators, connected directly or indirectly and delivers it to the distribution Systems or any selected final electricity user. The main characteristics of transmission systems (TS) are grouped in two areas: (a) Flows in transmission elements and (b) Voltage in the bus bars.

Flows are the amount of energy transmitted through any TS element, Lines and transformers are considered as main elements. Flows are a function of and depending directly on where the electricity is produced, where is consumed and the impedance of the TS between one location and the other. The physical characteristics of those locations as well as potentially different paths will result in different impedance.

It's noteworthy to mention that any TS do not follow any other rule besides the physical aspects of the systems. Ownership, control responsible or any other characteristic besides the one mentioned above has no influence to the flows circulated in the TS. In fact, the TS formed by voltage elements and connections among them becomes and will react as a single element in front of any change of topology, generation or load profiles. Thus, any grid study cannot be executed over a part of the system without considering the mutual impact of the rest.

A more interconnected system will display a higher strength and increased capacity to survive incidents and faults but at the same time more complex.

Solar power projects can be set up anywhere in the country, however, the solar power projects scattered in multiple locations lead to higher project cost per MW and higher transmission losses, due to drawing separate transmission lines to the nearest substation, procuring water and in the creation of other necessary infrastructure. Also, it takes a long time for project developers to acquire land, get a change of land use and various permissions, etc. which delays the project.

To overcome these challenges, and to facilitate the solar project developers to set up projects in a plug and play model solar park is most suitable zone.

The solar park is a concentrated zone of the development of solar power generation projects and provides developers an area that is well characterized, with proper infrastructure and access to amenities and where the risk of the projects can be minimized. Solar Park is also facilitating developers by reducing the number of required approvals assured availability of land and transmission infrastructure [1].

In India, Under the Solar Park scheme-Phase I, the Govt of India has sanctioned 34 solar parks having an aggregate capacity of 20,000 MW in 21 states. These parks are at different stages of implementation. Recent downward trends in solar tariff may be attributed to the factors like economies of scale, assured availability of land and power evacuation systems [2]. Based on the excellent response to the Phase-I of the scheme, the capacity of the scheme is enhanced from 20,000 MW to 40,000 GW. This will help in achieving the 100 GW target of solar energy which is part of India's upscaled 175 GW target of Renewable Energy by 2022 [3].

Now the challenge is whether India's electricity grid has the capacity to take intermittent power surges that will occur because of renewable energy. The grid should also have the capacity to carry power from regions where power is generated to the regions where power is needed.

In 2012, the government starts to build a Rs 38,000 crore green energy corridor to augment existing transmission infrastructure both within and across states. It is expected to be completed by 2019. For a project that has already had its share of delays and is being touted as the cure-all for grid issues, the renewable energy sector is aseptically if it will get done in time to make an impact [5].

### 20 GW Solar parks

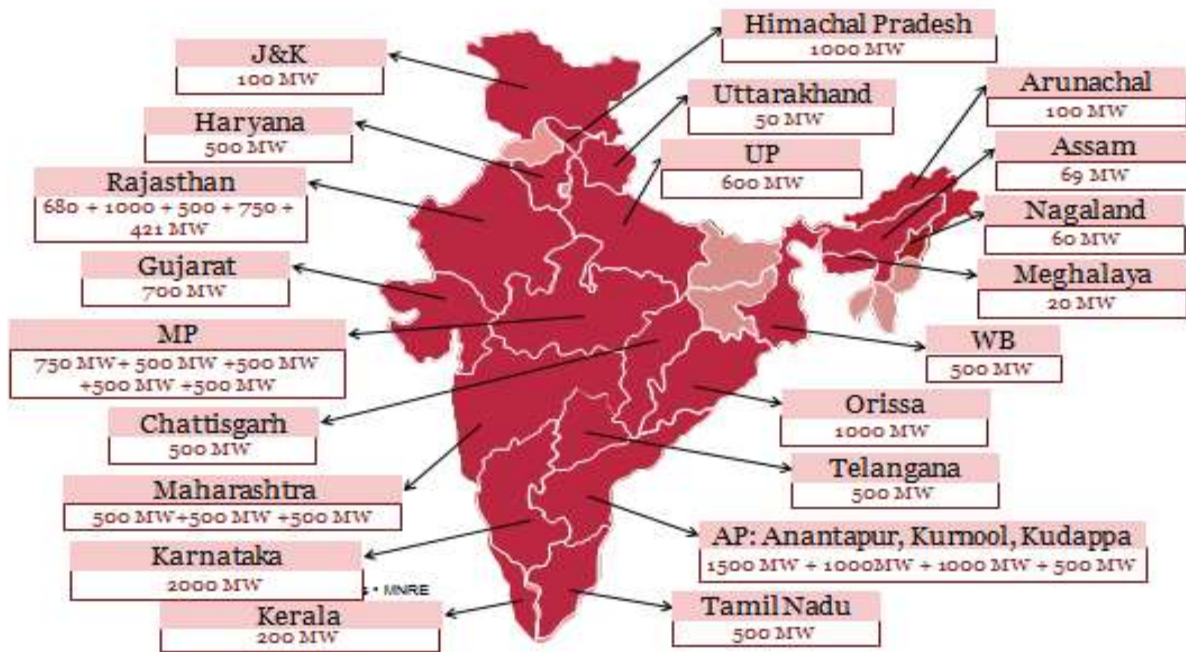


Figure 1 Solar Parks in India

Solar power projects in India have a "Must-run" status, which means they should be running at all times possible, given that there is no fuel cost when compared to thermal power projects which use coal. But solar plant operators were asked to "back down" or stop producing electricity several times, which is a disincentive for companies as they are not paid for the lost energy during that period [6].

The electricity transmission system receives the energy produced by all generators, connected directly or indirectly and delivers it to the distribution Systems or any selected final electricity user. The main characteristics of transmission systems are flows in transmission elements and voltage in the bus bars [7].

Flows are the amount of energy transmitted through any transmission system element in which lines and transformers are considered as main elements. Flows are a function of and depending directly on where the electricity is produced, where is consumed and the impedance of the transmission system between different location. The physical characteristics of those locations as well as potentially different paths will result in different impedance [8-10].

It is noteworthy to mention that any transmission system does not follow any other rule besides the physical aspects of the systems. Ownership, control responsible or any other characteristic besides the one mentioned above has no influence to the flows circulated in the transmission system.

In fact, the transmission system formed by voltage elements and connections among them becomes and will react as a single element in front of any change of topology, generation or load profiles. Thus, any grid study cannot be executed over a part of the system without considering the mutual impact of the rest. A more interconnected system will display a higher strength and increased capacity to survive incidents and faults but at the same time more complex [10-12].

Based on the above reference research work when a Solar Park is integrated into an interconnected system, flows will change not only in the nearby system but also in remote areas of the network. Assuming that the load will not change when a Solar Park is connected, the energy generated by the Solar Park will replace the generation of sources in other locations of the network which could be close or also far from the Solar Park. This replacement will modify most of the flows in the nearby and remote areas as well as in the areas between.

To better determine the flows, the security analysis shall consider the forecast of Renewable Generation, namely intermittent, as well as its variations due to weather conditions and thus determine the potential impact of those variations.

Part of the Security Analysis is the voltage control where in conventional systems the main control aspects are the power plants and as secondary the shunt devices and transformers tap changes, Part of the conventional plants which are great contributors to inertia and voltage control and low demanding

of ancillary services, will be replaced by intermittent renewable power plants, which require more ancillary services than conventional and provide lower voltage control. Solar plants and namely solar parks shall contribute, the more the better, to voltage control and even supplement this capacity with external elements like CVS or TRANSCOM.

## II. NETWORK PLANNING

Network planning is done considering normal network conditions regarding the generation and load profiles as well as the topology scenarios, which are considered based on the defined security criteria. In case there are delays in the transmission system expansion or reinforcement and at the

same time there is an unexpected generation or load profile and the security criteria are broken, then the only solutions are:

- a) Reduce the actual generation with impacts on the intermittent renewable energy sources
- b) Apply some countermeasures based on smart grid components (like variable impedance transformers as an example) or special protections schemes systems generation or load rejection or even split the system.
- c) Use demand side management as different tariffs for the consumers or even curtailments.



Figure 2 (a) Ananthapuramu Solar Park (b) Kurnool Solar Park



Figure 3 (a) 220/33 kV Pooling Sub-Station at Ananthapuramu Solar Park (b) 220/33 kV Pooling Sub-Station at Kurnool Solar Park





Figure 4 (a) Bhadla Phase II Solar Park (b) & (c) Control Room of Bhadla GSS (d) 400 kV Bhadla Substation

In figure 2 current installed solar modules of Ananthapuramu Solar Park and Kurnool Solar Park presented. In figure 3 220/33 kV Pooling Sub-Station at Ananthapuramu Solar Park and Kurnool Solar Park presented and figure 4 presents the current status of Bhadla Phase II Solar Park, Control Room of Bhadla GSS and 400 kV Bhadla Substation used in Bhadla Solar Parks.

### III. ANCILLARY SERVICES

Ancillary Services, defined as: "those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system."

The two most important ones are the

- a) Reserves of generation to support falls of generation and with the goal to maintain the frequency and interchanges in the case of loss of some generation.
- b) Maintain the voltage profile in the system

The units that better contribute in the Ancillary Services (AS) are the conventional rotating machines as combined cycles and hydro plant. Meanwhile, the ones that require more ancillary services are the intermittent renewable energies generation, with limited capacity for voltage control and almost null capacity to provide reserves.

As the integration of intermittent RE generation into the system will replace conventional generation. This implies more AS requirements. To integrate intermittent RE the reserves play a central role for System Security

### IV. SOLAR PARKS INTEGRATION

The impact of integration of solar parks into any system can be found in two main aspects of system security:

(a) *Global level:*

In global level system security, variations of generation over the scheduled will require more ancillary services than conventional generation, especially reserves, and regarding the size of the deviation, it will also impact the system

frequency. All these aspects will impact all interconnected systems. Global problems require global solutions; the unscheduled variations of generation represent a mismatch between load and generation. These deviations are corrected by the Ancillary Services as the first automated corrective action but will require rescheduling of the generation. The physical manifestation of this unbalance is a frequency deviation, as large as the generation deviation. This frequency deviation will impact the full interconnected system and in the case of India will concern all states.

The schedule of conventional plants is a function that depends on of the load forecast in the system and by the amount of non-scheduled generation, including the intermittent renewable energy generation and some potential "must run" units, as shown in the next schema:

(b) *Local level:*

In local level system security, flows will change day or night in comparison with the values registered before the Solar Park commitment. Also, voltage control will require more resources, up or down. Both aspects impact only the parts of the grid closer to the Solar Parks. Local problems require local solutions; the flows and voltage problems are felt in the closer electrical area of the network, but it still impacts the state interconnections, independently of the ownership of the network.

This graphic representation in figure 5 shows how important is the intermittent Renewable Generation forecast for the conventional generation scheduling and consequently the System Security.

### V. GLOBAL IMPACTS OF INTERMITTENT RE INTEGRATION

In general global problems shall be solved at interstate level, requiring coordination between the actions taken at Central level and at States level, while local problems shall be solved at the state level, requiring coordination between the load dispatch centers, local and state level.

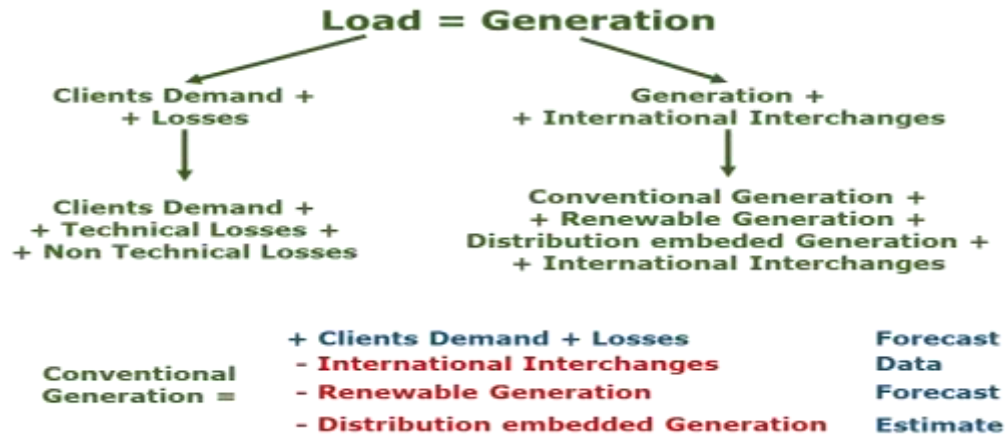


Figure 5 Graphical view of intermittent

The following aspects will be analyzed-

- a) Energy balance
- b) Intermittent renewable energy generation forecast.
- c) Frequency control
- d) Protection settings for voltage ride through capability

*(a) Energy Balance*

Energy balance is attained by the scheduling of generation units, which could be done at:

- i. **National Level**, where units under their responsibility will be scheduled, based on the forecast. Ancillary needs must consider the needs of the states along with the global needs. The national Load Dispatch Centre must guaranty that the interconnection capacity between states is not broken. It is possible that under certain conditions, some states can be grouped as a balancing area and work as a single system.
- ii. **At the state level**, where each State forecasts their own load and Renewable generation. With this information, the state load dispatch center can schedule the conventional generators and allocate the required ancillary services. Furthermore, it can program economic interchanges with other states, considering the interconnection capacity and the introduction of added system losses.

Solar Parks shall facilitate the information required by the Load Centres, either at a national or local level to adequately balance the generation with consumption and estimate the required ancillary services. Solar generation is primarily an energy resource which cannot be dispatched like a conventional generation. In more traditional utility operations, predictions of system load for the next hour, day, week, etc. are essential for programming supply resources so that total costs are minimized while maintaining system reliability and security. Incremental costs due to the uncertainty in the timing and quantity of energy delivery from intermittent renewable energy generation facilities in operational time frames that can

be reduced with the better short-term forecast. Solar generation forecasts and the appropriate use of those predictions by the load dispatch centers in scheduling functions and real-time operating practices will reduce the uncertainty.

As the penetration of renewable energies continues to increase and become a central piece of the energy mix, it will become increasingly important to consider ways to more efficiently operate power systems to accommodate significant amounts of such a variable resource. In situations where resource decisions are made according to various market signals, prediction of intermittent RE generation will be important for those who operate the markets and are in charge of system security and reliability.

Whether by the direct action of an operating entity or responding to market signals, electrical supply resources in any defined area must be managed, scheduled, and operated to provide the desired levels of system reliability and security. Furthermore, to minimize the overall cost of electricity to consumers in this area, the supply resources must be utilized in a manner that leads to the lowest total production cost. Meeting these objectives and at the same time honoring the countless constraints on individual generating units and resulting from contractual obligations requires the ability to continually assess the present state of the system and predict future states hours or days in advance.

Uncertainty in the operational planning time frame can lead to defensive operating strategies and higher costs. A solar generation without forecast will increase the uncertainty in the short-term forecasts of the system, leading to higher operating costs. In real-time operation, additional reserves might be allocated to cover the uncertainty in the hours ahead, again with higher costs.

In control areas with multiple intermittent RE generation facilities, forecasts must be generated for each plant on schedules appropriate for the real-time management of the control area as well as short-term operational planning

activities such as unit commitment or reliability monitoring. Given that the plants in a single control area may likely be exposed to the same general meteorological conditions, a wider geographical perspective on intermittent RE resource conditions for forecasting is essential.

*(b) Intermittent renewable energy generation forecast*

As a consequence of the introduction of solar PV generation, two main factors impact the operation of the power grid: diurnal cycle and localized effects. Diurnal effects are widespread, usually predictable, and relatively slow-varying events. Localized effects may induce sharp changes in the output of individual plants, which are caused by low, fast-moving clouds, rain or sand/dust storms.

Specifically, the irradiance measured at a certain location may vary of around the 80% in a very short term period (minutes). However, it is possible to assume, in the worst scenario, a ramp of 50% of the power per minute for 10 to 20 MW PV plants spread across a large area (square km). For larger plants having a wider geographical distribution, this effect could occur over a longer time frame with a lower magnitude.

Observation of 1-minute duration data shows that variability is essentially uncorrelated for about 1 MW PV arrays located at least 1 km apart. The geographical extension of the power plants over larger areas leads to the lesser correlation of cloud-induced ramps, even over larger time scales such as 5, 10 or 60 minutes. Therefore, variability in irradiance (and consequently PV generation) can be strongly mitigated when PV generation is geographically distributed across the power system. In fact, sharp ramp rates observed by irradiance sensors or in data collected at individual small PV plants show irrelevant effects at the transmission level. A Solar park will behave differently due to its size and relative narrow geographical location.

In the case of extreme weather events, like large sand storms or monsoon rains, being usually predictable, specific countermeasures can be taken in advance when necessary, such as:

- ❖ *Temporary increase of power reserve;*
- ❖ *Preventive power curtailments.*

Moreover, Energy Storage Systems installations can mitigate these problems as well; the installation of energy storage systems near a solar plant, solar park or on the system-wide scale should be investigated through a cost-benefit analysis. All the above-mentioned actions (storage, preventive power curtailments, and reserve increase) were successfully undertaken by some European transmission system operators or (mainly in Germany and Italy) during a solar eclipse in 2015.

In PV forecasting, weather variables that should be considered for day-ahead estimation are:

- ❖ Irradiance;
- ❖ Temperature.

❖ *Wind speed and direction*

Irradiance has the higher statistical correlation with the Actually Produced power as shown in figure 6.

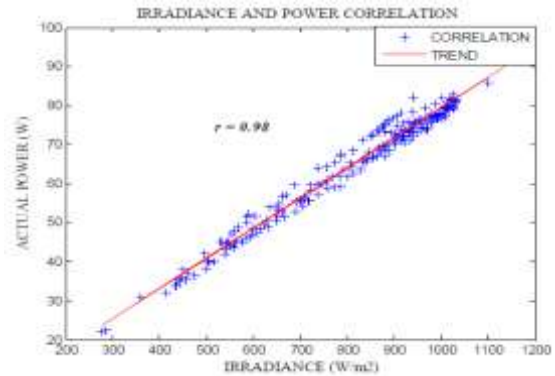


Figure 6 Correlation between power and irradiance

While the statistical correlation of the temperature and the generation is much less significant, it is clear that temperature impacts the generation by decreasing the efficiency of the PV plant.

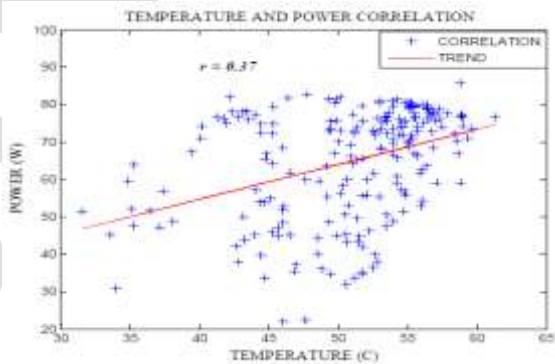


Figure 7 Correlation between power and Temperature

Several methodologies can be applied to PV forecasting, using both parametric methods (such as linear/multiple regression or time series) and artificial intelligence methods (such as neural networks and fuzzy logic). It also possible to extrapolate the total generated power by monitoring a certain number of "representative" units in each area. PV short-term variability should also be considered during forecasting and towards this end, the following is recommended:

- Embed the confidence interval calculation in the PV forecast algorithm;
- Study past behavior using actual output and weather records;
- Perform very short-term predictions with updated data.

*(c) Frequency Control*

Maintenance of the frequency among acceptable limits is a common job for all interconnected utilities. The first action is to match the generation to the actual load.

The frequency can be controlled by the generating utilities either manually or automated; the first one provides a basic control with low quality of the frequency at a reasonable cost while the second provides a very efficient control at a much higher cost.

The frequency stability will facilitate the interchanges among systems and the system operation with different units connected into the system.

*(i) Manual Control*

This methodology consists of a precise load forecast and a consistent schedule of generation. Unavoidably deviations in the demand forecast or in the generation will modify the load – generation balance that will produce fluctuations in the frequency. Its magnitude will be a function of the difference between the load and generation with regards to the size of the load.

To correct those deviations from the preset frequency value, some manual actions are taken either from the Load dispatch Centre or directly by the power plants, increasing or decreasing the generation as a response to a lower or higher frequency values.

Those methods to correct sensitive values of the frequency will never maintain the frequency at its precise value or correct the “electric time” as examples.

*(ii) Automated Control Load*

In antagonism with the previous system, the load – frequency control has as a mission, maintain the frequency value as close as the present value as possible, with a computer driven system for the generation control.

The system tries to correct to potential deviations, first the interchanges deviation as a difference between the scheduled and the actual interchange. By comparing both values, the difference is the error between the programmed and actual, also known as “Area Control Error (ACE). This value is split between the power plants that provide secondary reserve which will receive signals to raise or lower the generation if the actual value is lower or higher than the scheduled one.

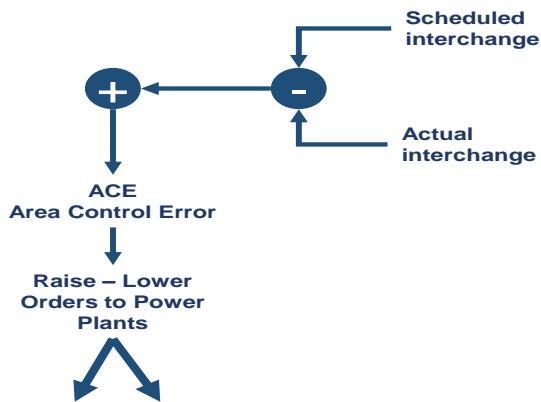


Figure 8 Area Control Error (ACE) model

The objective of this automatism is to maintain all interconnected systems fulfilling its interchange contracts inside acceptable limits and correct deviations as soon as they are detected. Within this system, there is not a corrective cooperation among the participants. In case one system deviates and is not able to correct, no other system will do it. The frequency will deviate until the whole system recovers all its margins.

To correct this situation and to establish cooperation between the participants as soon as the deviation is produced, a second branch is added to the previous schema: the frequency deviation correction.

The frequency deviation is multiplied by a factor called "bias frequency" that represents for each participant inside the synchronous area the weight of the load regarding the frequency, measured in kW/Hz. The Bias Frequency is a function of the size of the synchronous system and the size of each subsystem. The addition of the deviations for interchanges, detected only by the system deviated, and the frequency, detected by all interconnected systems, will provide positive reactions on all systems. When the frequency comes back to normal the rest of the systems will stop their support and the deviated system shall correct or reprogram their interchanges.

*Comparison*

Both options are effective and have been used in different transmission systems. To decide which one is more convenient for one system, some aspects shall be considered:

Load – frequency regulation is a more expensive system operation, equivalent to the cost of the reserves required to maintain the frequency as close as possible to the set point.

Load – frequency regulation results in a much more stable system and the potential oscillations are minor.

Wave quality is better in the case of a close control of the frequency while a loose control produces a lower quality wave profile.

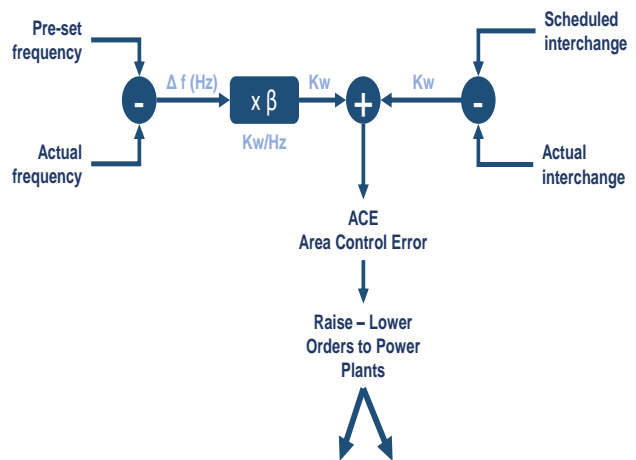


Figure 9 Area Control Error (ACE) detailed model

### VI. PROTECTIONS SETTINGS FOR VOLTAGE RIDE THROUGH CAPABILITY

Any short circuit in the system, even correctly eliminated by the protections system will generate a voltage dip. The main characteristics of these voltage dips are the “deepness” of the dip and the duration. The main aspects that define both parameters are the network conditions, the type of short circuit and the protections used in the system as shown in figure 10. The main objective is to study the actual capability of intermittent RE generators to “survive” voltage dips (holes), which is known as fault ride-through capability.

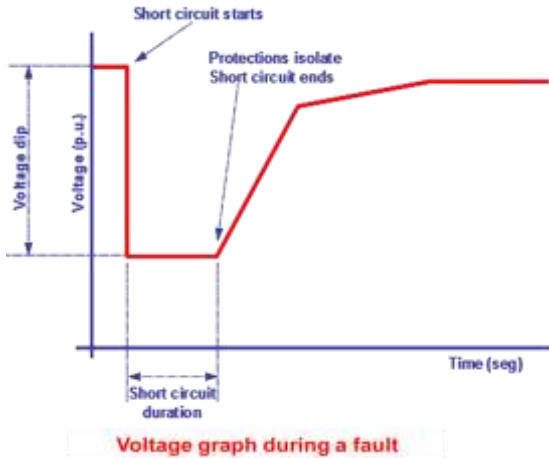


Figure 10 Voltage graph during a fault condition

In general, the generators will "survive" when the deepness and duration of the voltage dip are lower than those the generators can resist, according to their characteristics determined by the manufacturers and the protections settings. Some intermittent RE generators are technologically not adapted to have fault ride-through capability but even others that technologically may resist a dip hole may have characteristics or their protections set at values, which will not allow them to remain connected to the system. Solar parks have fault ride through capability, but the settings may allow them to "survive" or not as shown in figure 11.

It must be understood that the curve for a certain location during a short circuit depends on of many factors and will be different in all network locations as it depends on the resistance of the short circuit, short circuit power in each substation, network topology, impedance and resistance between the short circuit and the substation...

To calculate the real curve in the Parks locations, the easy way is one of the two following processes:

- i. Execute a dynamic simulation of the short circuits in the lines closer to the park substations, using a dynamic load flow, and considering the different protections settings in the Park and lines and transformers in the parking proximity.
- ii. Use the short circuit analysis tools to analyze the registered values of voltages and flows, during the short circuit.

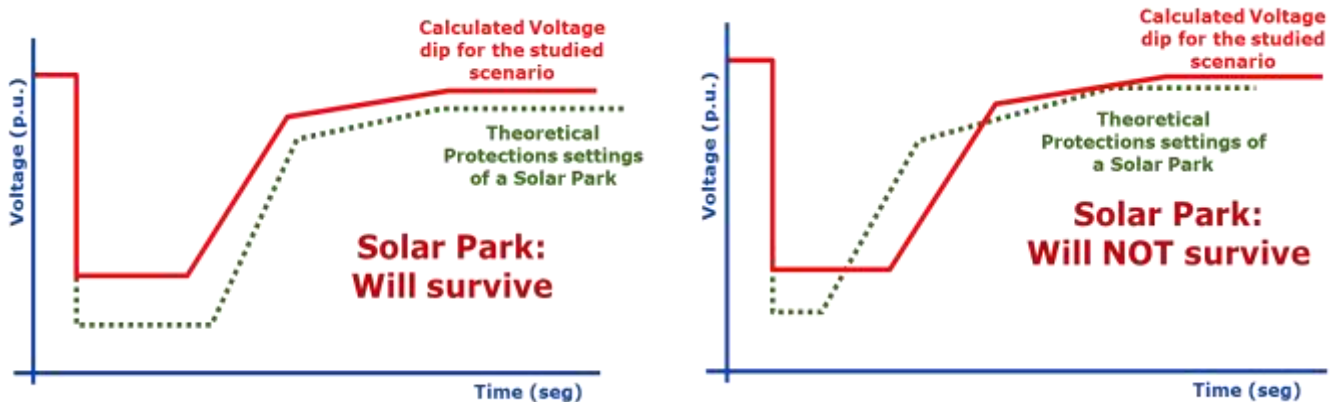


Figure 11 Case of surviving of solar parks

The best option combines the two alternatives.

If those options are not available due the lack of the dynamic model in the case i. or the unavailability of the short circuit analysis tools and approximation can be calculated from the settings of the network protections. Shortcuts in this process will impact into the Solar Park survivability to Short Circuits and in consequence to system security.

### VII. CONCLUSION

This paper has discussed system Security depends on the Solar Parks availability and the best possible generation forecast, current practices in power network investment planning and the need for improvements to data, methods, and tools to enable planning of a future power system. The Solar Park generation depends on the system Security. In the case of violations of the established security criteria, the operators are responsible for taking actions to correct such system condition and one of those measures could be the generation limitation



or curtailment. This mutual dependency requires that both sides know the decision-taking mechanisms for preventive actions. The impact of generation limitation into the Solar Park economy is too important to ignore it. In this research work integration techniques and global impacts the provision of methods and tools to allow the engineering questions to be addressed as conveniently as possible; decision making frameworks; provision of adequate skills among network planners and decision makers to manage data; development of requirements and specifications for techniques and tools for network planning to address the new challenges and provide the launch pad for diverse stakeholders to contribute;

The future system should accommodate greatly increased generation of power from low-carbon sources in such a way that the network cost is minimised while delivering desired levels of reliability of supply, primarily by means of minimising the requirement for new primary network assets and making greater use of network controls, in particular, to correct outcomes of disturbances.

#### CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this paper.

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