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Integration of wind farm in power system using STATCOM

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ABSTRACT -- The need for energy is an attention required issue for the developing countries. Developing countries are in the grip of the deficit of fossils or hydrocarbons sources of energy. Many countries are looking for the optimal solutions of energy production which are more reliable, pollution free and presume less cost. India is also in the list of those countries who want to get rid of expensive and polluted means of power production. Power production to fulfill the demand of the country is the biggest challenge for India. Wind farms interconnected to power system bring new challenges to power system economic operation. Wind power is going through a very rapid development. The integration of wind power in the power system is now an issue in order to optimize the utilization of the resource and to continue the high rate of installation of wind generating capacity, which is necessary so as to achieve the goals of sustainability and security of supply. This project presents the main technical challenges that are associated with the integration of wind power into power systems. These challenges include wind site selection, effects of wind power on the power system, the power system operating cost, power quality, power imbalances, power system dynamics, and impacts on transmission planning. The main conclusion is that wind power's impacts are most on systems power quality and power imbalances. To minimize this we use STATCOM , which is used to mitigate the effect of power imbalances.

Index Terms—IDVR, DVR, THD, STATCOM, Power Quality, Facts Devices, Power Imbalances, Matlab.

1. Introduction

The progress in wind energy technology has been extraordinary. The cost of electricity from wind power has fallen to about one seventh of the cost in the early 1980s [1]. This, added to worldwide growth in energy demand, environmental concerns, the rising cost of fossil fuel generation in many developing parts of the world, and a good wind resource base make wind a competitive option. In India as on 31 Dec 2010 the installed capacity of wind power in India was 13065.37 MW. But as on 31.08.2012 the installed capacity of wind power in India has raised to 17987.15 MW. A subsequent rise of 27.36 % in 18 months. In order to facilitate the implementation of wind power projects, various computer algorithms have been developed for the choice and design of wind power and other renewable energy sources [3], [4], [5], [6]. Three of the strongest challenges to wind power's future prospects are the problems of wind intermittency, grid reliability and voltage stability. The conventional management of transmission and distribution operation is challenged by electricity market restructuring, security of supply concerns and the integration of newer generation technologies such as wind power. Transmission availability can be a barrier to wind power development. Favorable wind locations are often in areas distant from existing transmission. Building new transmission lines can be difficult due to planning barriers, land use rights and costs.

Internationally accepted standards for power performance, safety, noise and other environmental-related conditions are needed to reduce market barriers, as well as administrative and installation costs. This paper presents the main technical challenges that are associated with the integration of wind power into power systems. These challenges include effects of wind power on the power system, power quality, power imbalances and power system dynamics.

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2. Wind Farm Site Analysis and Selection

2.1 Wind speed measurement

The device used for wind speed measurement is called an anemometer. There are three different techniques for wind speed measurement. In general, any measurable phenomenon that has strong dependence on wind velocity can be used for wind speed measurement. Experience has shown that thrust, pressure and the cooling effect are three most convenient parameters using which wind speed can be measured directly. A simple type of anemometer was invented (1846) by Dr. John Thomas Romney Robinson, of Armagh Observatory. It consisted of four hemispherical cups each mounted on one end of four horizontal arms, which in turn were mounted at equal angles to each other on a vertical shaft. The air flow past the cups in any horizontal direction turned the cups in a manner that was proportional to the wind speed. Therefore, counting the turns of the cups over a set time period produced the average wind speed for a wide range of speeds. The wind velocity has a linear relationship with the speed of rotation, which is measured by a photocell-operated digital counter. The display can be pre calibrated to give wind speed directly. Modern devices have facilities for continuous data logging and storage, from which data can be retrieved later for analysis.

2.2 Site and Turbine Selection

Site selection involves not only the choice of geographical location for a wind turbine or a wind farm, but also the model of the turbine that is best suited to a particular site. For the final selection process, that is, while choosing the wind turbine that is best suited for a particular site, a modification of the curve shown in figure 4 is necessary. At this stage, we plot the speed duration-curve. Naturally, the largest coordinate on the y axis is the number of hours in a year (8760), when the wind speed exceeds zero. If the wind speed is measured using a digital recorder with data logging facility, the wind speed distribution and duration curves can be obtained directly or generated by a computer later using the stored data

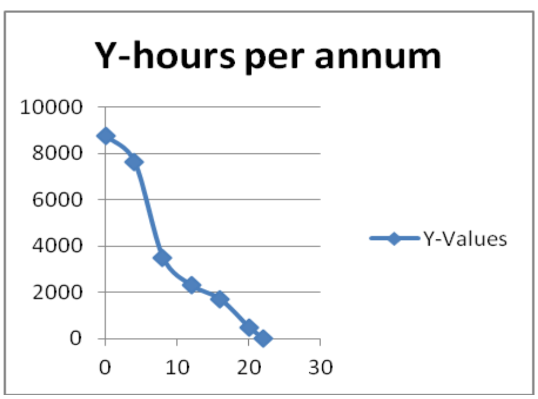

Figure 1.The wind speed duration curve: plot with wind speed along the x-axis and the duration for which the wind speed equals or exceeds that speed along the y axis.

Every wind turbine model has a specific cut in speed, a rated speed, a furling speed and power versus wind speed characteristics within the wind speed range between the cut-in speed and the furling speed. At the cut in speed the wind generator starts generating power. As the wind speed increases the power output increases in proportion with the power contained in the wind. After the rated speed is reached, the speed-regulating mechanism comes into action and there is a region of constant speed. Beyond a certain wind speed, the maximum power handling capacity of the generator is reached and thereafter the system works in the constant-power output mode. In some machines the constant-speed region is small and the speed regulating mechanism works only on constant power mode. In such cases the characteristics can be approximately expressed as

$$P(\mathbf{v})=\begin{cases}0.5\eta C\rho AV3, & \text{for } Vc \leq \mathbf{v} < Vr\\ 0.5\eta C\rho AVr & \text{for } Vr \leq \mathbf{v} < Vf\end{cases}$$

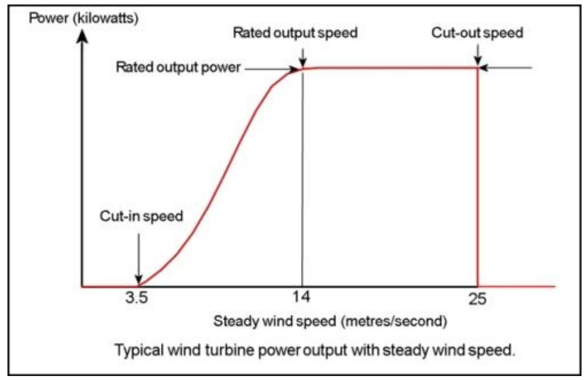

Figure: 2

3. Effects of Wind Power on the Power System

Regarding the power system, the drawbacks of wind power are that wind power production is variable, difficult to predict and cannot be taken as given. However, integration of variable sources is much less complicated if they are connected to large power systems, which can take advantage of the natural diversity of variable sources. A large geographical spreading of wind power will reduce variability, increase predictability and decrease occasions of near-zero or peak output. The power system has flexible mechanisms to follow the varying load that cannot always be accurately predicted. As no production unit is 100% reliable, part of the production can come from variable sources, with a similar risk level for the power system.

The impacts of wind power in the electricity system depend to a large extent on the:

- Level of wind power penetration;
- Grid size; and
- Generation mix of electricity in the system

Wind energy penetration at low to moderate levels is a matter of cost, as demonstrated by various national and regional integration studies. And the integration costs related to the impacts listed above are fairly modest. For low penetration levels of wind power in a system, system operation will hardly be affected.

The established control methods and system reserves available for dealing with variable demand and supply are more than adequate for dealing with the additional variability at wind energy penetration levels of up to around 20 per cent, depending on the nature of a specific system. For higher penetration levels, some changes to systems and their method of operation may be required to accommodate the further integration of wind energy.

Short and long term impacts

The impacts of wind power on the power system can be categorized into short and long-term effects. As shown in table 2. The short-term effects are caused by system balancing at the operational timescale (minutes to hours), whereas the long-term effects are related to the contribution wind power can provide to the system adequacy (its capability to reliably meet peak load situations).

Impacts in the system: Local and system wide

Locally, wind power plants interact with the grid voltage, just like any other power station. In this context, steady state voltage deviations, power quality and voltage control at or near wind farm sites must all be taken into consideration. Wind power can provide voltage control and active power (frequency) control. Wind power plants can also reduce transmission and distribution losses when applied as embedded generation.

4. Power quality

The location and intermittent nature of wind turbine machines can cause power quality problems such as voltage dips, frequency variations, and low power factor. Wind turbines, especially inductive machines, tend to absorb reactive power from the system and produce a low power factor. If wind turbines absorb too much reactive power, the system can become unstable.

Poor power quality can cause the end user's equipment to operate inefficiently, i.e. lights to flicker, or the utility system becomes unstable and disrupts power to the customer. Power quality problems caused by wind power are best solved at the point of interconnection of the wind generator to the utility grid [8]. New state-of-the-art wind generators utilize power electronics and variable-pitch turbines that allow the wind turbine to produce energy at various wind speeds [9]. The same power electronics regulate the turbine's output voltage while keeping the power factor close to unity. The power electronics in the turbine control the voltage and phase angles of the rotor's currents to control the output voltage and power factor. In the past, utilities relied on switched capacitors to keep the voltage steady and maintain power factor. However, switching capacitors could only provide fixed amounts of volt–ampere reactive (VAR) and tended to put stress on the wind turbines gearbox and increase its cost of maintenance. The power electronics in new wind turbines provide the appropriate amount of VARs without stressing the wind turbine gearboxes. In addition to adding power electronics inside the wind turbines, some utilities are looking to DC and voltage source converter (VSC) to connect the wind turbines to their grid to stabilize the voltage and frequency.

5. Power Imbalances

The power fluctuation at each wind turbine is affected by the type of turbine, the control algorithm, the wind speed fluctuation, and the tower shadow effect. The power measurement from a single wind turbine usually shows a large fluctuation of output power. Because many turbines are connected in a wind farm, the power fluctuation from one turbine may cancel that of another, which effectively rectifies the power fluctuation of the overall wind farm. As wind energy technologies progress, wind turbines become larger. Manufacturers are currently producing multi mega watt wind turbines. Thus, fewer turbines are needed to deliver the same power and the power fluctuation of an individual wind turbine will have a greater impact on the power network. The impact on a weak grid will be even greater. We used a simulation program to investigate the impact of the turbine distribution on a large wind farm. Many researchers have investigated various aspects of electrical power systems on a wind farm. Wind farms with variable speed or fixed speed wind turbines were investigated under varying conditions. The voltage fluctuations as a function of X/R ratio, the reactive power fluctuations on voltage variation, the harmonics components at the point of common coupling (PCC), and the flicker emission out of a wind farm were presented in reference [5] and reference [6]. The flicker emission from a wind farm is reduced as the grid stiffness (Sk/Sn ratio) increases [6]. Also, the flicker emission is affected dramatically by the turbulence intensity. The flicker emission at 16% turbulence intensity is twice as high as a turbulence intensity of 8% [7].

6. Effects of wind power on power system dynamics

Power system dynamics investigates how a power system responds to disturbances that change the system's operating point. Examples of such disturbances are frequency changes because a generator trips or a load is switched in or disconnected; voltage drops due to a fault; changes in prime mover mechanical power or exciter voltage, and so on. The power system is considered stable if the system reaches a new steady state and all generators and loads that were connected to the system before the disturbance are still connected. The original power system is considered unstable if, in the new steady state, loads or generators are disconnected.

The dynamics of a power system are governed mainly by the generators. Thus, if conventional power generation with synchronous generators is on a large scale replaced with wind turbines that use either asynchronous squirrel cage induction generators or variable-speed generation systems with power electronics, the dynamics of the power system will at some point be affected, and perhaps its stability, too. Although wind turbines indeed affect the transient and small signal dynamics of a power system, power system dynamics and stability are not a principal obstacle to increasing the penetration of wind power. By taking adequate measures, the stability of a power system can be maintained while increasing the wind power penetration.

In the case of constant-speed wind turbines, measures must be taken to prevent voltage and rotor speed instability in order to maintain transient stability. This can be done by equipping them with pitch controllers in order to reduce the amount of over speeding that occurs during a fault; by combining them with a source of reactive power to supply the large amount of reactive power consumed by a squirrel cage generator after a fault, such as a static condenser or static VAR compensator; or by changing the mechanical and/or electrical parameters of the turbine [10]. In the case of variable-speed wind turbines, the sensitivity of the power electronic converter to over currents will have to be counteracted in another way than is presently done, namely, by switching off the turbine. However, the literature seems to indicate that there may indeed be other options.

The small signal stability shows that increased levels of wind power penetration do not seem to require any additional measures in order to maintain small signal stability. The generator type that is most likely to engage into power system oscillations is the synchronous generator, and that generator type is not used in the wind turbine types that are presently on the market. Therefore, replacing synchronous generation seems to have either a negligible or a favorable impact on power system oscillations. However, the impact of wind power on the small signal stability of power systems is a rather recent research subject. Hence, results are still very limited. Therefore, the conclusions presented here should be considered preliminary and be used prudently.

7. Voltage Sag/Swell, THD Compensation using IDVR and STATCOM

All Power Electronic based utilities are very sensitive in nature because of its switching condition; due to this most of the harmonics are generated during unbalanced, sudden change in load. Power quality issues such as voltage distortions, sag/swell will arise due its utility equipments may get damaged, so some external devices has to be used to compensate the issues. The voltage source inverter based dynamic voltage restorer is connected with three phase transmission line to compensate the variations in voltage like voltage sag/swell by injecting three phase voltage into transmission line.

The magnitude and phase angles of the injected three phase voltage can be varied, thereby allowing control of real power and reactive power exchange between the DVR(dynamic voltage restorer) and the distribution system. The amount of real power and reactive power provided by the DVR depends upon the type of voltage disturbance occurred due to load variations, the power requirements of the protected load and the direction, magnitude of the injected three phase voltage. The mitigation of the voltage sag/swell is mainly dependent upon on device connected in series with the line and the energy storage to the supply when the DVR comes into operation. DVR is compensating the voltage sag even for long duration effectively. The progressive phase advance technique where all the three phase voltages are progressively advanced by a certain angle α to reduce the amount of real power supplied by the DVR. The injected three phase voltage of the DVR depends upon the accuracy and dynamic behavior of the pulse width modulated (PWM) voltage synthesis scheme and control system used.

The general requirement of such control scheme is to obtain an AC waveform with low total harmonic distortion (THD), which can be minimized using STATCOM. A shunt connected FACTS device called STACOM can also be used to minimize the THD generated due to the electronic loads. STATCOM is preferred due to its simplicity, low cost, effective reactive power compensation. Reactive power compensation is required for grid connected wind energy farms.

Basic Operational Principles of DVR, IDVR and STATCOM

The dynamic voltage restorer is a series connected device, which by voltage injection can control the load voltage. In the case of a voltage dip the DVR injects the missing voltage and it avoids any tripping the load.

The DVR considered consists of:

- An injection/ series transformer
- A harmonic filter

- A voltage source converter (VSC)
- An energy storage
- A control system

8. STATCOM – STATIC COMPENSATOR

The STATCOM (or SC) is a shunt connected reactive power compensation device (FACTS device) that is capable of generating and/ or absorbing reactive power and in which the output voltage can be varied to control the specific parameters of an electric power system. The STATCOM basic diagram is shown in figure 9. It is in general power electronics based solid state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals. When it is feed from an energy source or energy-storage device (battery) at its input terminals. The DC voltage is provided by an energy-storage capacitor.
A STATCOM can improve power-system performance in such areas as the following:

- The dynamic voltage control of transmission and distribution network systems
- The power oscillations damping in power transmission network systems
- The transient stability control
- The voltage variation control
- The control of not only reactive power but also real power in the connected transmission line required a DC energy source.

Furthermore, a STATCOM does the following:

- It occupies a small footprint, for it replaces passive banks of control circuit elements by compact power electronic converters
- It offers modular, factory – built equipment, thereby reducing site work and installation time
- It uses encapsulation power electronic converters, thereby minimizing its environmental impact.

Simulink using MATLAB.

The proposed model for STATCOM was used to create a simulink in MATLAB. In which a wind turbine was connected with a STATCOM (FACTs) device. So obtain a constant 3 phase power supply at the output for increasing wind speed and constant wind speed signal. It was observed that without using STATCOM the active and reactive power vary with change in speed of wind. This reduced the stability of the power system used in wind farm. But on using STATCOM the output for increasing wind speed and constant wind speed, remained constant i.e. the active power changed with input signal, but the reactive power remained constant and we got a constant 3 phase supply. Figure 3 shows a Turbine and STATCOM model.

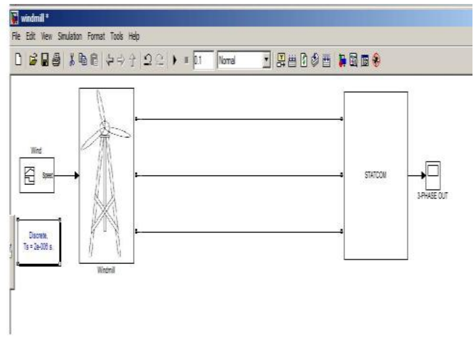

Figure 3. Turbine and STATCOM model

STATCOM model is shown in figure 4. This contains an AC-DC-AC converter inverter circuit. This is used to convert varying AC voltage to a constant AC voltage and current waveform.

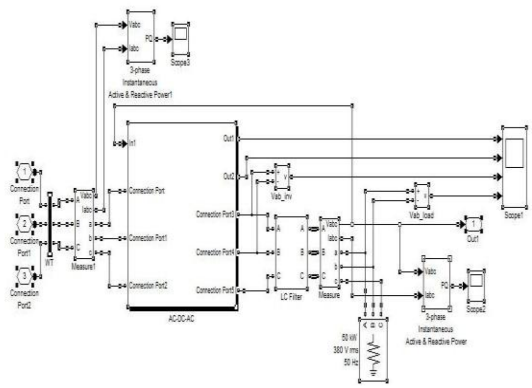

Figure 4 STATCOM MATLAB Model

RESULTS:

For constant speed signal.

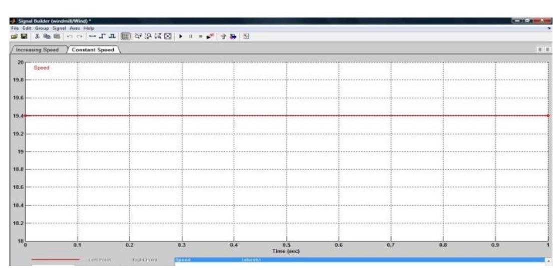

Figure 5. Constant Speed Signal

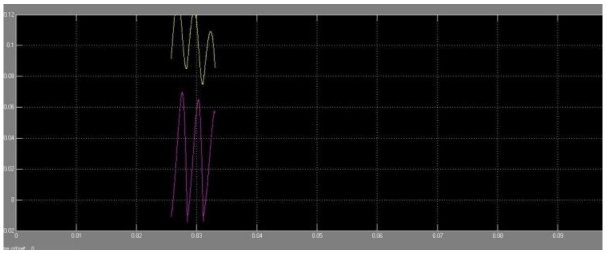

Figure 6. Active power and Reactive power graph without using STATCOM

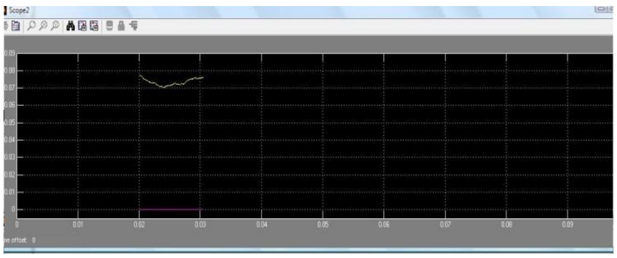

Figure 7 Active power and Reactive power graph using STATCOM

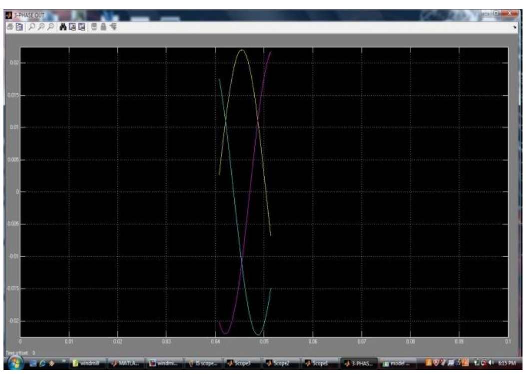

Figure 8. Constant 3 Phase output for constant speed signal

For Increasing Speed Signal

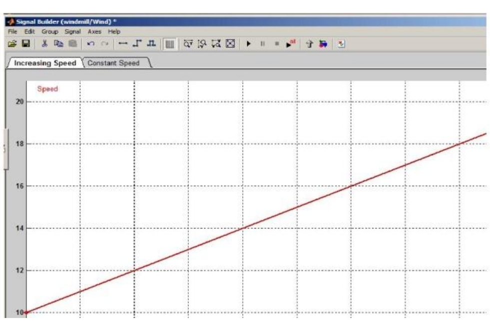

Figure 9. Increasing Speed Signal Generator

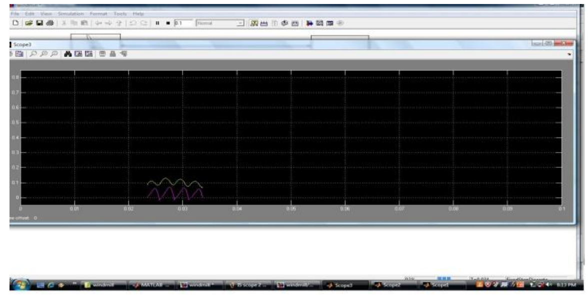

Figure 10. Active power and Reactive power graph for increasing speed without using STATCOM

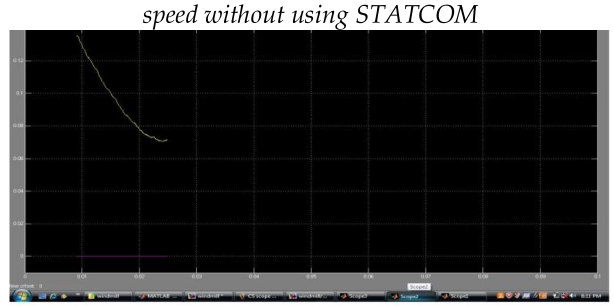

Figure 11 Active power and Reactive power graph for increasing speed using STATCOM

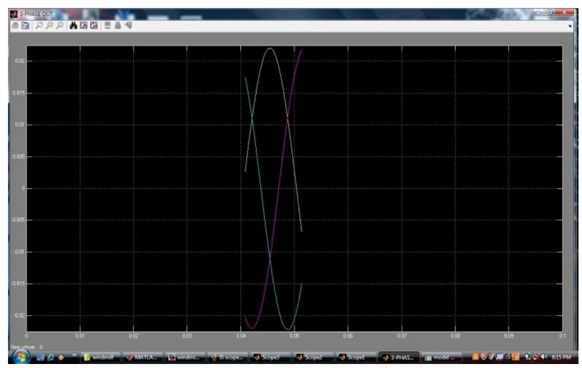

Figure 12 3 phase power output using STATCOM

9. Conclusions

The main technical challenges that are associated with the integration of wind power into power systems were presented in this paper. These challenges include effects of wind power on the power system, the power system operating cost, power quality, power imbalances, power system dynamics, and future of wind energy in India. Work conducted to date shows that wind power's impacts on system operating costs are small at low wind penetrations (about 5% or less). In most cases, these incremental costs would detract from the value of wind energy on current wholesale markets by 10% or less. At higher wind penetrations, the impact will be higher, although current results suggest the impact remains moderate with penetrations approaching 20%. What remains is to integrate these techniques into the day-to-day operation of power systems. On any given power system, costs arising from wind variability are a strong function of the characteristics of the system, such as generation mix and fuel costs, and will increase with increasing wind penetration, assuming the non-wind characteristics of the system remain unchanged, by using STATCOM model the instability due to varying speed can be reduced to considerable effect.

10. Future Scope

The main problem that arises in integration of wind farm with existing network is of power imbalances or frequency regulation. This in turn is affected by variable speed of wind turbine. So model which can work using VSC techniques and Power electronics can be integrated which will help in generating power at constant speed irrespective of speed of wind turbine. The techniques that can be used have been shortlisted are DVR, IDVR and STATCOM. A proposed model in which both STATCOM and Pitch Angle Control can be formed to control the power imbalances.

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