Fully Automated Wind Project: Automating the Substation

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Abstract - **For years, turbine manufacturers and third parties have provided wind farm management systems that automatically control the wind turbine/generators. Unfortunately, these systems are connected to interconnecting substations that may have remote control capabilities, but they are completely manual and require operator intervention for restoration.**

The wind resource is not available for generation if a typical momentary grid outage occurs. This unavailability of the wind resource is easily corrected with a substation automated restoration system.

For any substation problem, manual restoration is appropriate, but for utility line outages, which are the most common, an automated restoration system brings the project back on-line in minutes without operator intervention. The project and the utility can benefit from the automation. The equipment required for the automation is often already part of the protection system so the additional hardware costs are minimal. Operators may use the automated system restoration to minimize human error when energizing the substation after a utility outage.

A fully automated project (turbines and substation) can fully restore itself in 10 minutes or less. Any outage time due to the loss of the utility source is minimized – providing maximum generation availability.

Our energy future is made more secure by making our energy sources more available.

I. Introduction

One of the common occurrences for distributed generation, and particularly wind turbine farms, is the loss of the utility grid. When this occurs the generation is shut down and the lost revenue clock begins ticking. If the outage occurs late at night on a weekend and the restoration is performed manually, the lost revenue for one outage can easily be in the tens of thousands of dollars. The impetus therefore to minimize outage time is directly related to the return on investment for the distributed generation owner/developer.

Since modern wind turbines are connected by fiber optic communication links that permit remote monitoring and control of each turbine, the capability to automatically restart the turbines is readily available. Also modern digital relays and reliable logic processors are now common place in the modern substation. The real-time digital information from the protection relays coupled with the timing and logic functions of the logic processor, inherently lend themselves to automatic restoration of the substation when safely appropriate after an outage. By monitoring the state of the power system circuits, devices and systems within the substation, the appropriate sequence, timing and reconnection to the grid can be automatically controlled for all realistic operational scenarios of the substation, including restoration.

II. Terminology and Definitions

There a number of terms and acronyms frequently encountered in the renewable energy sector. For this paper the following terms are used and defined:

1. CF – Capacity Factor: The ratio of actual average power generation in megawatts to the maximum rated power capability of the installed turbines and is directly related to the wind speed and duration for the turbines under consideration (25% to 40% capacity factor is typical).

2. DR – Distributed Resource: Sources of electric power that are not directly connected to a bulk power transmission system. DR includes both generators and energy storage technologies.[1]

3. DG – Distributed Generation: Electric generation facilities connected to an area electric power system (EPS) through a point of common coupling (PCC); a subset of distributed resources (DR). [1]

4. EPS – Electric Power System: Facilities that deliver electric power to a load. An EPS may include generation units. The EPS may be a local power system or be an area power system. [1]

5. GTG – Generation-to-Grid Factor: The percentage of time that generation is actually connected to the grid and represents a composite of the availability of the wind, planned and unplanned outages, utility remedial action and any other factors that may limit the amount of time that the DR may be connected to the grid (65% to 80% is typical).

6. ICS – Interconnection System: The collection of all equipment and functions, taken as a group, used to interconnect a distributed resource (DR) unit to an area electric power system (EPS). [1]

7. IED – Intelligent Electronic Device: Any microprocessor-based unit that receives voltage, current, status or other data from sensors and power equipment, and can issue output commands if they sense anomalies. Common types of IEDs include microprocessor based relays, recloser controllers or other electrical power equipment controllers.

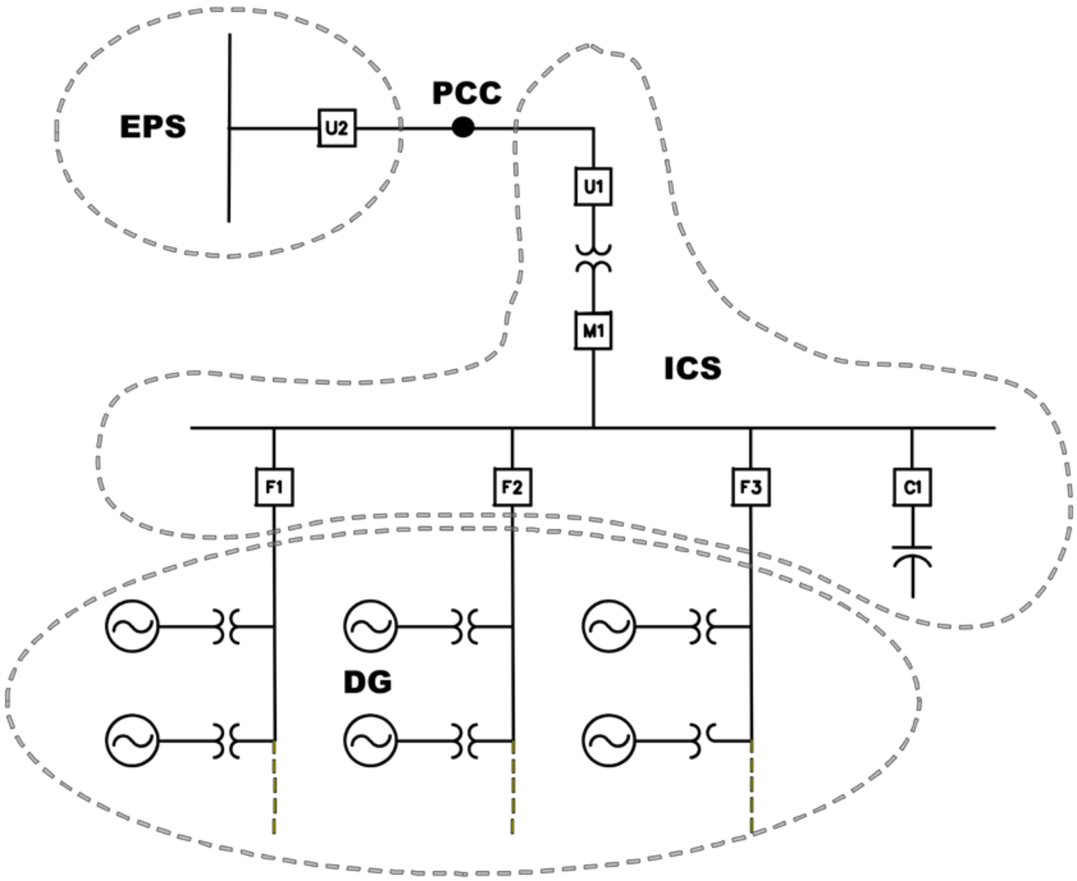

FIGURE 1 – Typical Intertie with Elements Associated with Acronyms Identified

8. PCC – Point of Common Coupling: The point where a local electric power system (EPS) is connected to an area EPS. [1]

The various sub-system elements of an intertie with their associated acronyms are shown in Figure 1. The distributed generation (DG) is a sub-element of a distributed resource (DR). The area electrical power system (EPS) is typically the nearest utility. The DR is connected to the EPS through the ICS. Together the DR and ICS form a local EPS and where the area EPS ownership ends and the local EPS begins is the point of common coupling (PCC). This may also be referred to as the point of service (POS) where the metering for energy sale takes place. Not shown in the diagram are the IEDs within the ICS sub-system.

III. Prior Applications

Similar control systems have been applied to utility distribution stations to minimize customer outages.[2] These proven systems have reduced outage time and reduced the labor required for system restoration and fault diagnostics. Using similar concepts with additional considerations for the DGs, automatic restoration may be applied to wind projects.

IV. Typical Auto-Restoration Scheme Hardware

The hardware essential to auto-restoration consist of the following essential elements (See Figure 2 for interconnection arrangement):

A. Sensor and Status Inputs - The potential and current transformers that provide the scaling of the power level electrical energy systems for substation protection and control are the “eyes and ears” that provide the real-time information necessary for auto-restoration. Also important are status contacts of the power devices and equipment that control the flow of real and reactive energy within the substation. By monitoring the substation voltages, currents and status contacts the necessary information is available for the decisions necessary for auto-restoration. In most cases this hardware is already part of the substation and does not add to the investment cost for auto-restoration.

B. IEDs (Relays) - The intelligent electronic devices of the substation are the bridge between the sensors and the high voltage power equipment

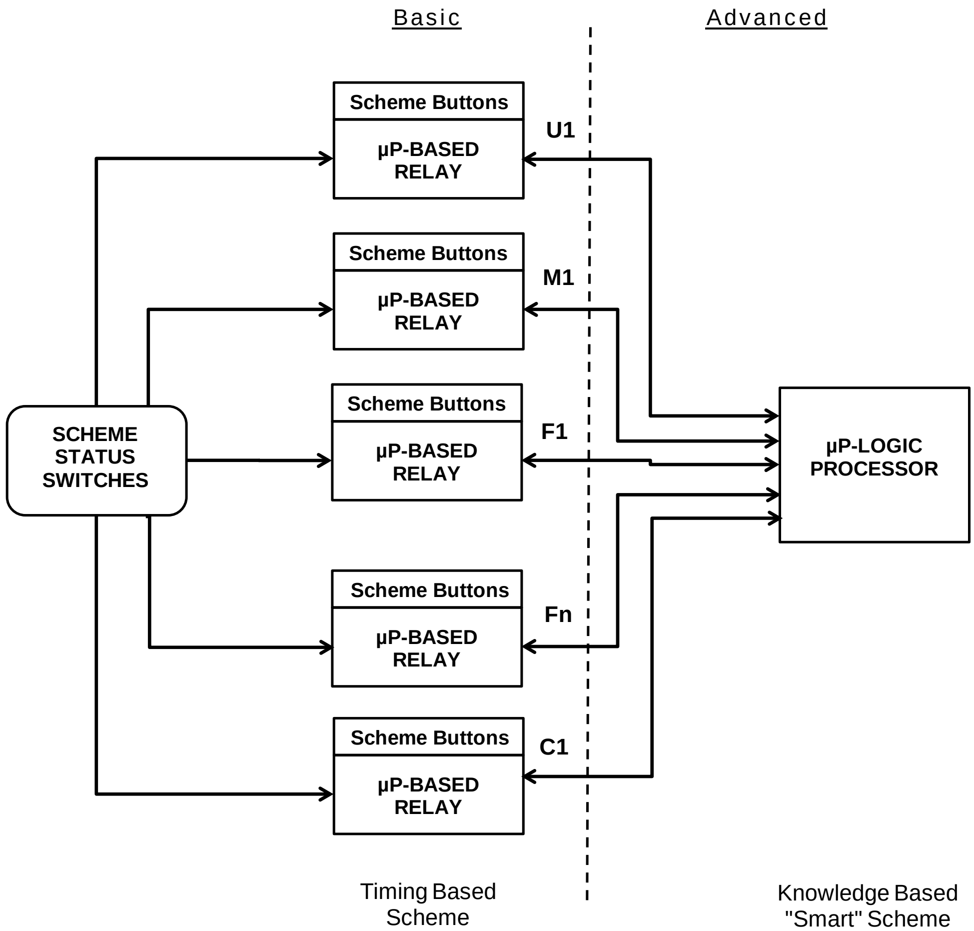

FIGURE 2 – Typical Auto-Restoration Scheme Hardware

within the substation. These IEDs are typically a variety of digital relays, digital logic processors, communication processors and real-time controllers. The signals from the sensors are interpreted in a systematic and pre-determined way so that the system power devices are energized, de-energized or otherwise controlled appropriately. The digitized analog values, status bits, timing functions and logic functions that are integral elements of the substation IEDs are leveraged to add auto-restoration capability to the substation. Although few if any IEDs must be added to perform auto-restoration, there is effort necessary to program the IEDs for auto-restoration. Standardization of the IED schemes minimizes the effort to programming, test and commission the IEDs, and therefore the cost, to implement auto-restoration.

C. IEDs (Logic Processors) – If the relays are connected to facilitate communication of various system statuses and parameters, they can make more informed decisions about the auto-restoration. If a logic processor is used to connect the relays, it can add common timing and logic relevant to multiple relays.

D. Outputs to Power Devices - Just as sensors provide inputs to the IEDs for the auto-restoration scheme, outputs to the power system equipment provide the control signals that energize the circuits for auto-restoration. The DR energy is then able to flow to the grid. This is the final step in the scheme that permits the DR energy to do useful work and become a marketable commodity. The power devices are an integral part of the power system and adding control for automation is a marginal cost compared to the value of the power devices.

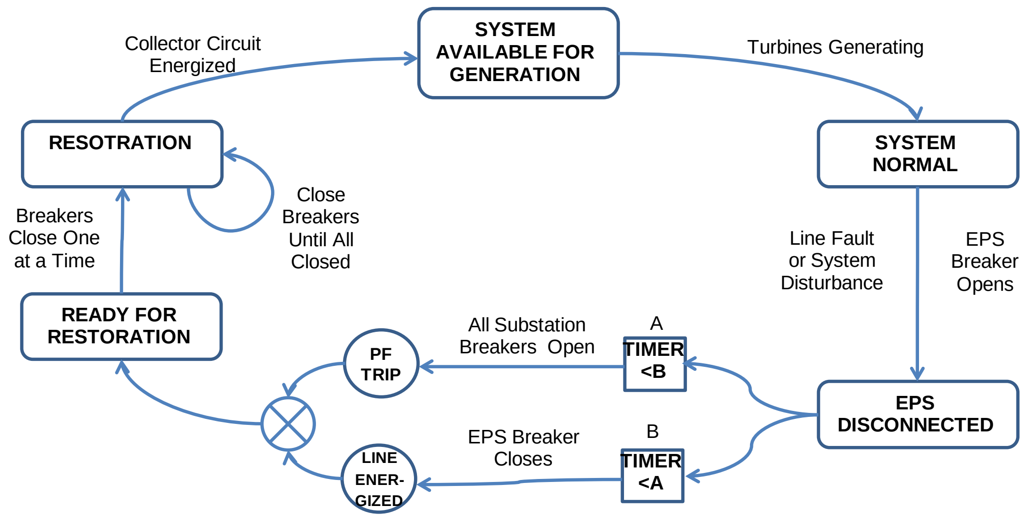

FIGURE 3 – Typical Auto-Restoration State Flow Diagram

V. Auto-Restoration State Flow Diagram and Operational Description

One way to more fully understand and appreciate a fully automated wind project is to follow the state flow diagram for a typical wind project. See Figure 3 for a typical state flow diagram for an auto-restoration cycle. The operational sequence begins with the state "System Available for Generation" (see top of the diagram). This is the preferred state where the turbines are generating and the system is normal and providing electrical energy to the utility grid as indicated by the next state "System Normal." When there is line fault or system disturbance the EPS breaker (Breaker 'U2" in Figure 1) will open and the system is now in the next state, "EPS Disconnected." In this state the flow of energy to the grid has ceased and the electrical energy that would normally be available from the wind is no longer marketable. During the transition to the next state to make the turbines again available for generation, two timed sequences are activated simultaneously. First, a "Power Fail Trip" status (labeled "PF Trip" in the Figure 3 diagram) is declared three (3) or more seconds after the loss of three-phase voltage. All relays for the line, feeder and capacitor breakers are programmed with this status and all line, feeder and capacitor breakers are opened at this time. The EPS breaker closes after utility has cleared the fault or disturbance, and the power fail trip operations have completed. The system state is now "Ready for Restoration." The line breaker (Breaker 'U1" in Figure 1) will close if the following conditions are all true after a set time delay:

- Auto-restoration switch is in the "enabled" position (this is typically an operator controlled switch in the substation)
- The line-side motor operated switch is closed
- The line is live and load-side bus is dead
- All feeder/capacitor breakers are open
- All Lock-Out Relays (LORs) are reset
- All communications are working properly
- There is no close failure on the main breaker
- The has been no trip within 15 minutes of the last close
- The line breaker was not manually opened or tripped due to breaker failure or backup over-current condition

After the line breaker is closed, the feeder breakers will automatically close with similar closing criteria listed above one at a time with pre-determined time delays. Typically, all the feeder breakers close in ten (10) second intervals so that all feeders are restored within one or two minutes. Once all feeder breakers are closed the collector substation returns to the "System Available for Generation State." The total outage time for a fully automated collector project (turbines and substation) is typically ten (10) minutes or less. Any outage time due to the loss of the utility source is minimized and therefore provides optimized generation availability.

VALUE FOR AUTO-RESTORATION

Energy Rate	ER	0.075		$/KWHr
Generation Capacity	RC	100		MW
Capacity Factor	CF	33		%
Generation to Grid Time	GTG	70		%
Hours Per Year	HPY	8760		Hrs/Yr
Yearly Gross Revenue	YGR	$21,681,000	*	$/Year
Value per Available Hour	HV	$3,536	**	$/Op Hr
Average Manual Restoration Time	MRT	12		Hrs
Auto-Restoration Time	ART	0.1		Hr
Value of Auto-Restoration Per Event	**VAR**	**$42,075**	*******	**$/Event**

* =ER*RC*1000*(CF/100)*HPY

** =YGR/(HPY)/(AV/100)

*** =(MRT-ART)*HV

FIGURE 4 – Typical Auto-Restoration Versus Manual Restoration Value

VI. Auto-Restoration Economics

The value of the optimized generation availability can be calculated by the economic advantage of reduced outage time provided by auto-restoration over the longer time required for manual restoration. For a typical 100 MW wind farm with 33% generation capacity, connected to the utility grid 70% of the time, the value per hour for lost delivery to the grid when generation would otherwise have been available is $3500 per hour at 7.5 cents per kilowatt-hour. If manual restoration requires twelve (12) hours before restoration can be accomplished, then the total energy value for this example is $42,000. This example is summarized in Figure 4. It should be noted that this represents only the economic energy advantage and does not take into account the avoided cost for labor and vehicle expenses that are incurred with manual restoration. Manual restoration cost includes accounting for the time for an operator to be notified of the outage, the operator to travel to and from the collector substation, analyzes the reason for the outage, and then perform the restoration. The savings may be less than twelve hours if the manual restoration can be accomplished in good weather when an operator is readily available, but on a weekend night in inclement weather the time for manual restoration can be one or two days. After considering all these factors it is not difficult to recoup the investment for the auto-restoration investment after only one or two line outages.

VII. Maximum Benefit

As discussed in the introduction, wind turbine control systems have the ability to automatically restart after the loss of the utility source. However, this ability may be a programming option in the turbine control systems and in some cases the turbine control system may require operator acknowledgement of the loss of grid power for each turbine. If an automatic restoration system is applied at a wind farm substation, the wind turbine control system engineer should be informed so as to take full advantage of the system.

VIII. Summary Conclusions

The provision for auto-restoration on distributed generation, particularly for utility-scale wind farms, has been shown to be very feasible with the micro-processer based relays and communication processors already being used to protect the collector substation that is part of every renewable energy project. With renewable energy very much dependent upon the “up-time” and delivery of energy to the grid, auto-restoration provides a very good way to accelerate the return on the large capital investment required for renewable generation. With only marginal additional investment the addition of auto-restoration may pay for itself in as few as one or two outages.

References:

[1] IEEE Std 1547.1-2005 “Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems,” New York, NY, The Institute of Electrical and Electronics Engineers, Inc.

[2] Tatera Jr., Bernard S., Pacific Gas and Electric Company and Larry Gross, Relay Application Innovation, Inc., “Implementation of a New Substation Restoration System Using Protective Relays and a Logic Processor,” Paper presented at the Western Power Delivery Conference, Spokane WA, April, 2001.

Author:
Lawrence (Larry) C. Gross, Jr., P.E. is President of Relay Application Innovation, Inc. He is a professional electrical engineer with experience in power system protection, operations, protection integration, technical training, and technical writing. He has performed services for relay manufacturers, utilities, industrial plants, and design consultants. The services include protection coordination studies, microprocessor based relay settings, protection scheme design, generation interconnection protection, substation automatic restoration scheme design, commissioning support, relay performance analysis, and relay communication and application design for point-on-wave closing control specific to the wind industry. Larry has been involved with over 50 wind projects throughout the U.S. since 2002. Originally registered in California in 1995, Larry is currently registered in fifteen (15) other states. He holds a patent for “Circuit for Protection Against Slow Circuit Breaker Closure During Synchronization of a Generator and an Associated Electrical System.” He has authored several application guides, technical presentations and technical papers on power system protection, monitoring, and control.
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