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CELLULAR COMMUNICATIONS FOR UTILITY DISTRIBUTION NETWORK FIELD ASSETS

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Abstract

A cellular router is used to transmit data from a control center to field assets through an IPsec tunnel. Transmission occurs via a secure path inside an unsecure network. Data is routed using distributed network protocol (DNP) via ethernet and serial connection through a real-time automation controller (RTAC). The RTAC acts as a data concentrator to allow for multiple reclosers to be polled and operated remotely and efficiently through one hub. The RTAC establishes tag processing, binary control operations, and DNP class 0 polling hierarchy. The recloser receives polling and control demands and responds, returning data along the same path.

Introduction

Outages happen. When they do, these outages are very costly. In the worst cases – the outage that started the Camp fire, for instance – power outages can lead to loss of life in addition to the billions in economic impact, with rural areas being the most susceptible to the impact due to their geographic distance from infrastructure hubs. Minimizing the time these outages occur can in turn minimize the associated disaster risk. Adopting cellular communication in transmission and distribution (T & D) systems can improve the ability to reach rural locations that are cost prohibitive using traditional communication methods. This project will explore the opportunities to use cellular communication for controlling and monitoring T & D equipment. The goal is to demonstrate the feasibility of remotely controlling reclosers via wireless and serial communication for electric power utility-scale application. This will be done by performing successful remote control of a recloser in a lab setting and showing scalability.

Solution

There is a way to make cybersecure and utilize the network which is already part of our everyday lives – cellular – and apply its existing infrastructure to a scalable, reliable, and cost-effective approach to the problem. Figure 1 shows the system block diagram for this project.

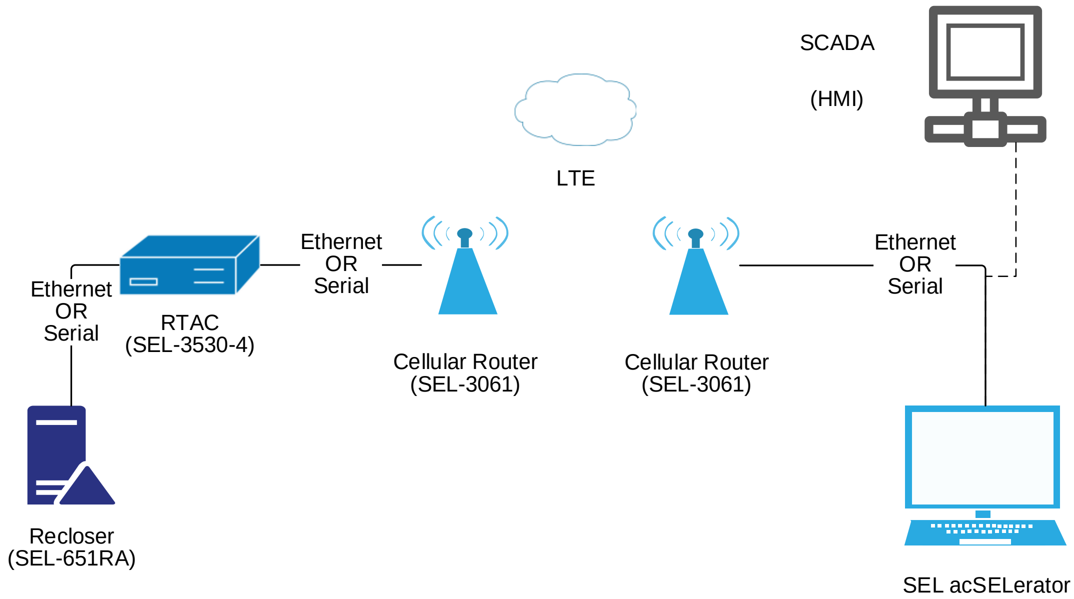

Fig. 1 – System block diagram

The recloser is connected to one cellular router via the RTAC and the other cellular router sits in a control center where the laptop acts as the Supervisory Control And Data Acquisition (SCADA) master. Figure 2 shows the system setup as it appears in the lab.

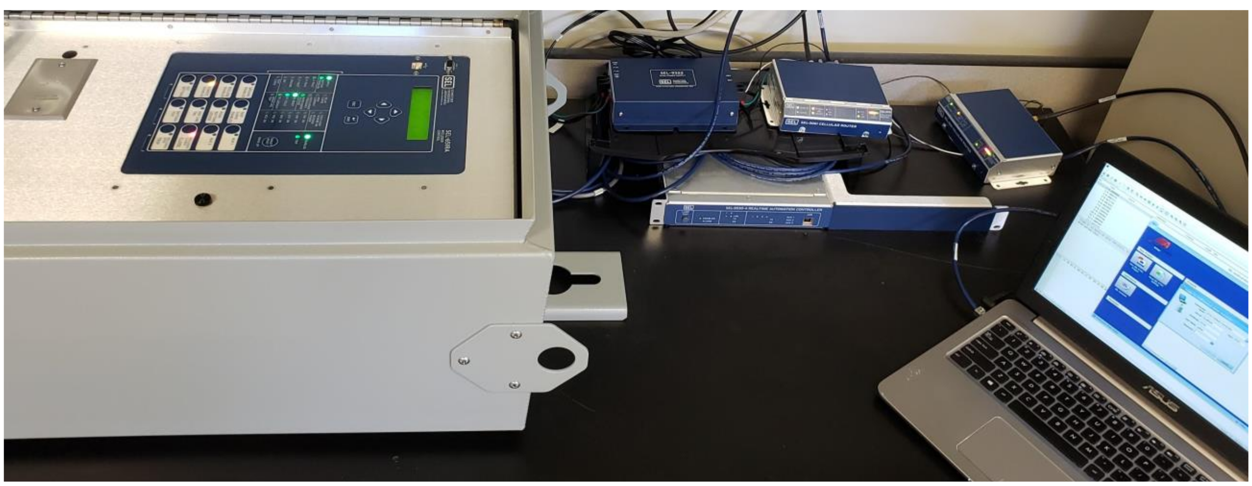

Fig. 2 – In-lab setup

A microgrid was created using SEL acSELerator software to simulate a real T & D system. Different communications paths are used throughout three phases of the project. Due to ethernet being routable, it is easy to work with but not very cybersecure. These properties make it ideal for testing, but not for real-world applicability. Thus, after ethernet communication is successfully achieved, the project will shift to RS-232 serial to attain cybersecurity. Figure 3 shows the communication progression throughout the three phases.

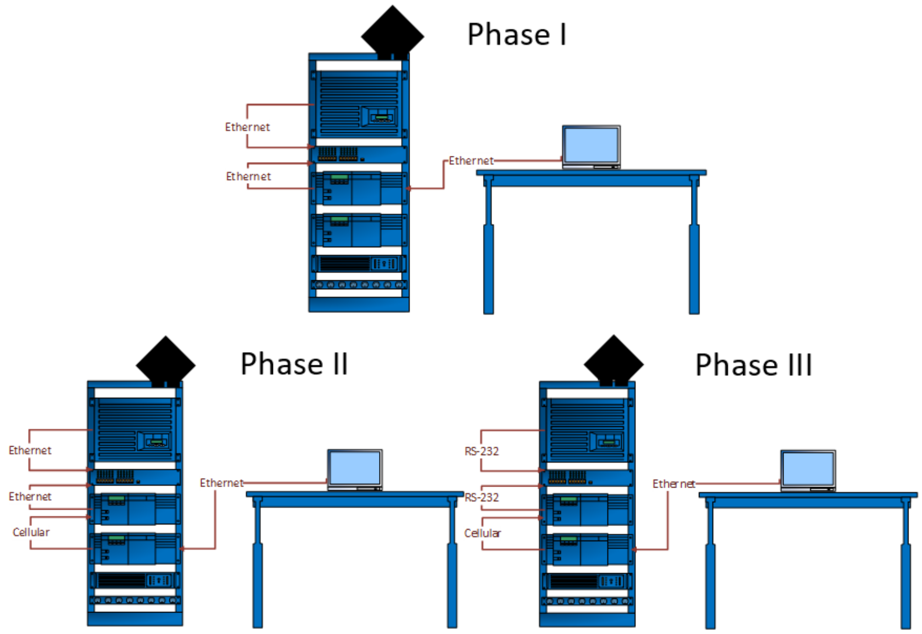

Fig. 3 – Communication medium progression

SCADA can be used to facilitate control and data gathering between field assets and substations. Many substations today have SCADA as well as some level of intelligent electronic devices (IEDs) – whether that be a meter, or an RTAC – anything that can communicate real-time information with field assets like relays, reclosers, etc. and the field assets to make them useful. Currently, there is no way for local utilities to remotely issue control commands directly to the field assets via the IEDs with which they communicate. The status quo is that remote access to these devices is read-only for cybersecurity purposes, meaning that a control center can poll data but has no control over field assets. This project aims to offer a cybersecure way to facilitate remote control of field assets from a control center.

Consideration of external constraints

T & D lines have been alleged to be the cause of several recent wildfires. Remote recloser control may help mitigate T & D related wildfires by providing faster response and earlier detection when coupled with other protection equipment. If T & D related wildfires can be reduced or prevented altogether, there could be huge health and safety benefits. Many lives are lost each year to wildfires, as well as homes evacuated. T & D related wildfires have been the cause of businesses being negatively impacted. Preventing them can have a positive effect on the economy. There is high political and regulatory visibility on this subject. This project is being funded through Department of Energy (DOE) grants.

Methods

Figure 4 illustrates both the existing methods for outage recovery, and the new method proposed by this project. Currently, the electric utility still finds out about outages in many areas from customer reporting. The utility may not even know an outage exists until you call them if there is no SCADA in your residential area, which is especially common in rural areas. Then, once the utility finds out about the outage, a lineman must drive to the location of the outage, locate the fault, call it in to someone at the substation or return there themselves, interrupt power, remove the fault, and then have power restored. This can take up to a whole day, even for something minor. This project seeks to establish a new method of remote control from a control center. If recloser control is desired, the modem will then send a data packet through cellular service. The LTE network will carry the data through to a cell pack that is serially connected to the relay or recloser controller. The recloser can either interrupt or restore the circuit based on operator input. Coupled with a smarter grid that includes line sensors and automatic switching, this could reduce outage recovery time by a factor of 6!

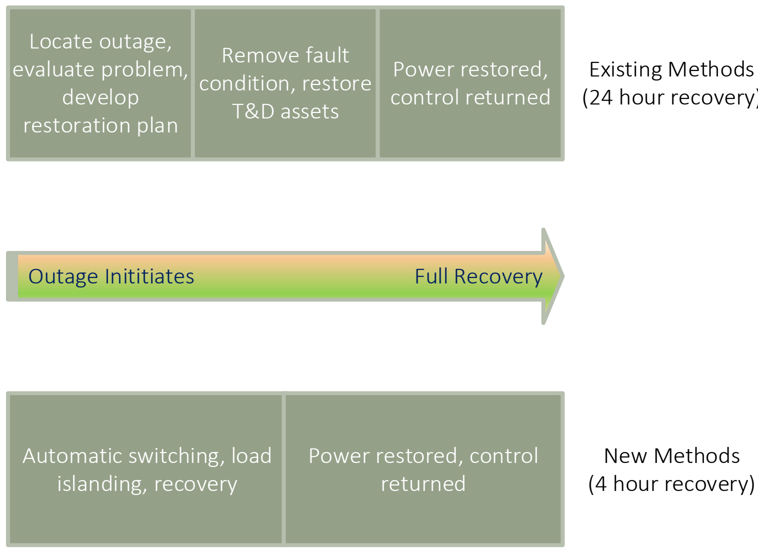

Fig. 4 – Outage recovery

There's a reason this level of sophistication doesn't exist everywhere on the grid – cost. The installation of communications, especially in rural areas, can be cost prohibitive due to the geographic distancing between consumers. Even in more populated areas it can still be quite expensive to have high quality communications installed. Furthermore, places like Utah which have mountainous terrain, can present obstacles to certain forms of communications which require line of sight (LOS). Figure 5 displays the different communication methods that were analyzed for their feasibility in this project.

Method	Pros	Cons
Telephone Line	Private, reliable	Expensive, slow
Cellular	Inexpensive, doesn't rely on LOS	Inconsistent
Radio	Unlicensed, fast	Requires LOS
Fiber Optic	Very fast, video compatible	Very expensive
Microwave	Fast, large bandwidth	Requires LOS, subject to weather interference
Ethernet	Reliable, inexpensive	Limited range

Fig. 5 – Communication methods

79 Lockout is part of the control state for reclosing. Because the lab setup didn't connect the recloser to a live relay, the reclosing logic had to be reprogrammed using SELogic control equations to enable access to operate the recloser. The trip logic equation for the sensor which is responsible for detecting relay activity was reprogrammed to a combination of latches and binary states. It is important to note that this reprogramming needs to be undone before the recloser can be used on a live system. Figure 6 shows the face plate of the recloser controller, which has indication of the 79 Lockout relay.

Fig. 6 – SEL-651RA face plate

Figure 7 depicts the custom-designed human machine interface (HMI) that was built for this project. Using AcSELerator RTAC software, this HMI maps hundreds of binary, analog, and counter tags to the recloser to enable anyone familiar with the equipment instant access to relay control as well as critical system data. Used in a control center, this gives remote access to operate and monitor dozens of parameters using a simple push button system. Each pushbutton, LED, and data point is mapped to the appropriate tag in the polling map. While this was not part of the original scope of the project, the alternative makes clear this is a massive upgrade. Unfortunately, to upload this to the system one must be directly plugged into the RTAC and, in conjunction with COVID-19 and the subsequent lab closure, this portion of the project never came to fruition. However, it is still fully functional and ready to go.

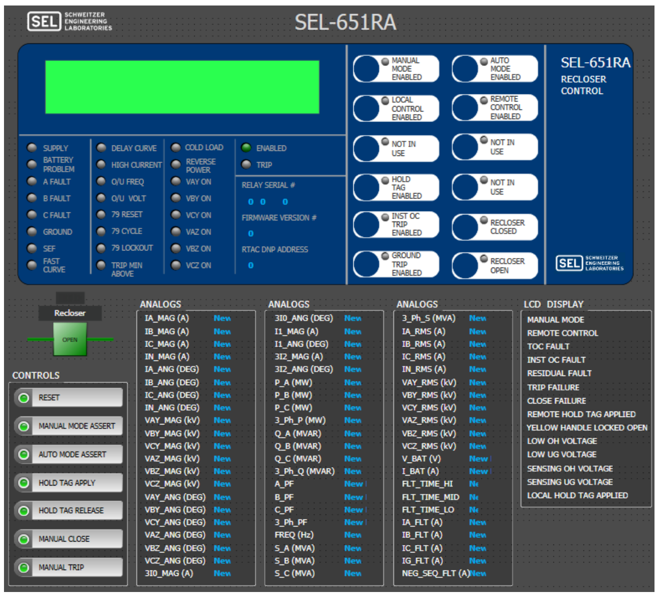

Fig. 7 – Custom-designed HMI

The cellular routers needed to be configured to allow for a cybersecure communication path. There is an interactive dashboard which was used to configure and monitor router communication data. System cybersecurity was established via a virtual private network (VPN) IPSec tunnel and a firewall filter rule. The IPSec tunnel provides a secure communication path within an unsecure network, while the firewall filter rule ensures only the two cellular routers can access their ports. The result of the configuration is that the two routers can communicate only with one another and reject all other incoming requests. This prevents other devices from entering the private network.

Results
This project had the following goals:

- DNP TCP poll over LTE:
  - Class 0 to serial communication to recloser
  - Operate relay command to serial communication to recloser
  - Class 0 to wireless serial communication to recloser
- DNP TCP poll over VPN:
  - Class 0 to TCP communication to recloser
  - Operate relay command to serial communication to recloser
  - Class 0 to wireless serial communication to recloser

Additionally, the following methods of control were achieved:
1. Local, manual operation
2. Via serial communication from laptop to recloser
3. Via ethernet communication from laptop to RTAC to recloser
4. Via ethernet communication from laptop to cellular router, wireless communication over IPsec VPN, to serial communication to recloser

100% of the target objectives for this project were met. Utilizing the IPsec VPN: Class 0 polling to TCP communication, Class 0 polling to wireless serial communication, and successful relay operation command to the recloser controller were consistently achieved. Figure 8 depicts data packets between the two cellular routers indicating successful Class 0 polling and relay operation command.

54	46.000621	192.168.1.2	192.168.1.7	DNP 3.0	103	Select
55	46.002706	192.168.1.7	192.168.1.2	TCP	68	20000 → 37984 [ACK] Seq=560 Ack=388 Win=8109 Len=0 TSval=3615451050 TSecr=4345586
56	46.003741	192.168.1.7	192.168.1.2	DNP 3.0	105	Response
57	46.003894	192.168.1.2	192.168.1.7	TCP	68	37984 → 20000 [ACK] Seq=388 Ack=597 Win=664 Len=0 TSval=4345589 TSecr=3615451050
58	46.004737	192.168.1.2	192.168.1.7	DNP 3.0	103	Operate
59	46.006790	192.168.1.7	192.168.1.2	TCP	68	20000 → 37984 [ACK] Seq=597 Ack=423 Win=8074 Len=0 TSval=3615451050 TSecr=4345590
60	46.007938	192.168.1.7	192.168.1.2	DNP 3.0	105	Response
61	46.047182	192.168.1.2	192.168.1.7	TCP	68	37984 → 20000 [ACK] Seq=423 Ack=634 Win=664 Len=0 TSval=4345633 TSecr=3615451050
62	50.000469	192.168.1.2	192.168.1.7	DNP 3.0	92	Read, Class 123
63	50.002173	192.168.1.7	192.168.1.2	TCP	68	20000 → 37984 [ACK] Seq=634 Ack=447 Win=8050 Len=0 TSval=3615455070 TSecr=4349586
64	50.003928	192.168.1.7	192.168.1.2	DNP 3.0	135	Response
65	50.004142	192.168.1.2	192.168.1.7	TCP	68	37984 → 20000 [ACK] Seq=447 Ack=701 Win=664 Len=0 TSval=4349589 TSecr=3615455070
66	50.005064	192.168.1.2	192.168.1.7	DNP 3.0	83	Confirm

Fig. 8 – Wireless communication data packets showing polling and operation

Conclusion
With all target objectives met, utilizing cellular communications for increased access to utility field assets is feasible. Class 0 polling and relay control over IPsec VPN successfully demonstrates a reliable, scalable, cost-effective, and cybersecure solution to building infrastructure in rural and mountainous terrain to minimize effects of outages.
The DOE is investing money in the Utah STEP ARMS project to, among other things, implement this very technology into Utah's electric grid to make it smarter, more efficient, and safer. Future research should focus on scalability and field testing.

Acknowledgements
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