MOBILE SUBSTATION DESIGN

Brad Bozich & Vitor Vieira
2755 Northwoods Parkway
Norcross, Georgia 30071
678.982.8928
brad.bozich@efacec.com

SCOPE

This document is intended to help define the main parameters used to specify Mobile Substations, and discuss features and limitations according to the desired application. Additionally it points out some of the critical constraints to take under consideration while trying to achieve the best possible solution capable of assuring the utility requirements.

CODES AND STANDARDS

Standards of the American National Standards Institute (ANSI) and IEEE must be followed. Except as otherwise noted, all apparatus furnished hereunder shall conform to all applicable rules of the foregoing standards whether or not specifically mentioned.
In addition to the industry standards, the apparatus furnished hereunder shall comply with applicable Federal and State laws, codes, and regulations.

Each mobile substation shall be designed and constructed for safe, proper and reliable operation in an outdoor environment regardless of actual location of installation and in areas accessible to the general public. Only materials best suited and tested for the respective applications shall be used. Workmanship and shop inspection shall be high quality.

The following list of ANSI/IEEE C57 & C37 Series standards are especially important in the design of transformers and ancillary equipment covered by this specification but is by no means a definitive or complete list of all applicable standards.

IEEE C57.12.00	Standard General Requirements for Liquid-Immersed Distribution, Power and Regulating Transformers
ANSI C57.12.10	American National Standard for 230kV and Below, 833/958 through 8333/10417 Single Phase and 750/862 through 60000/80000/100000 kVA without Load Tap Changing and 3750/4687 through 60000/80000/100000 kVA with Load Tap Changing - Safety Requirements
ANSI C57.12.70	American National Standard Terminal Markings and Connections for Distribution and Power Transformers
IEEE C57.12.80	Standard Terminology for Power and Distribution Transformers
IEEE C57.12.90	Standard Test Code for Liquid-Immersed Distribution, Power and Regulating Transformers and IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers
IEEE C57.13	Standard Requirements for Instrument Transformers
IEEE C57.13.1	Conformance Test Procedures for Instrument Transformers

IEEE C57.13.3	Guide for the Grounding of Instrument Transformer Secondary Circuits and Cases.
IEEE C57.19.00	Standard General Requirements and Test Procedure for Outdoor Power Apparatus Bushings
IEEE C57.19.01	Standard Performance Characteristics and Dimensions for Outdoor Power Apparatus Bushings
IEEE C57.19.101	Guide for Loading Power Apparatus Bushings
IEEE C57.98	Guide for Transformer Impulse Tests
IEEE C57.104	Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers
IEEE C57.106	Guide for Acceptance and Maintenance of Insulating Oil in Equipment
IEEE C57.113	Guide for Partial Discharge Measurement in Liquid Filled Transformers and Reactors
ANSI C37.30	IEEE Standard Requirements for High Voltage Air Switches
ANSI C37.32	American National Standard for Switchgear - High Voltage Air Switches, Bus Supports and Switch Accessories - Schedule of Preferred Ratings, Manufacturing Specification and Application Guide
ANSI C37.33	American National Standard for Switchgear - High Voltage Air Switches Rated Control Voltage and Their Ranges
ANSI C37.34	American National Standard for Switchgear - Standard Test Code for High Voltage Air Switches (including supplements a through e) NEMA SG6 NEMA Standard for Outdoor High Voltage Switches NEMA 107 Methods for Measurement of Radio Interference Voltage (RIV) of High Voltage Equipment
IEEE 1268.2005	Guide for the Safe Installation of Mobile Substation Equipment
IEEE C2.2007	National Electrical Safety Code

DEFINITION

Mobile substations are used by utilities around the world, providing a solution for emergency, temporary, maintenance or construction power.

A mobile substation (or portable substation) can have several configurations depending of the utility, manufacturer, standards, environment and region of the world where it will be used. Since highway restrictions vary from state to state, it is difficult to adopt a standard design for a mobile unit. Therefore, close coordination should be exercised among the purchaser, the design engineers, and the state highway commissions.

A mobile substation is composed by a wide range of equipments according with the application desired by the customer.

POWER TRANSFORMER

The power transformer is the most important piece of equipment in a Mobile Substation, its technical specifications will play a major role in the characteristics of the Mobile Substation. The weight and size of the power transformer are the main restriction to the design of the trailer.

Transformer MVA

Due to the need for compliance with transit legislations and physical limits to the maneuverability of the Mobile Substation, the allowable power transformer's rating is inferior to the one of a fixed transformer. It is unusual to have a power transformer for a mobile substation rated higher than 60 MVA.

The main restriction to the power transformer rating is the weight and dimensions of the equipment. Higher ratings usually lead to higher weights and dimensions and consequently to a greater difficulty to attain permits to move the mobile and also to longer trailer's which impacts the maneuverability.

Multiple Voltages/Voltage Regulation

Mobile substations frequently have multiple voltages. The presence of tap changers (OLTC or DETC) has a very significant impact in terms of dimensions and weights. It's mandatory to determine if OLTC and/or DETC are to be included. Multiple voltages are more easily implemented if they're achievable by series-parallel windings.

OLTC can be located in the HV or LV winding according to manufacturer criteria in order to achieve a lighter, more compact, and short-circuit resistant unit.

The location on the LV side some time implies the need to include a preventive auto to limit the current in the OLTC contacts that ads weight, making some times preferable to have the OLTC in the HV winding.

Transformer Cooling

In order to minimize the dimensions of the power transformer while maximizing the available power it's usually preferred to have ODAF cooling. Other types of cooling (ONAN, ONAF, etc.) may still be used (it may also be possible to maintain the power transformer full MVA rating without cooling, but this will only be possible for a short duration before it leads to the deterioration of the power transformer's insulation).

The objective of the cooling system is to allow the dissipation of the heat resulting from power transformer's load losses.

MOBILE SUBSTATION MOUNTED ON TRAILER(S)

This is the traditional configuration of a mobile substation. All of the equipment is installed on one or

more mobile trailers to be transported by road according to the customer's requirements.

In this configuration all HV, MV and LV substation equipment is installed on a mobile trailer.

MOBILE TRANFORMER
Only the power transformer and cabinets are installed on the trailer or platform. Auxiliary services transformer can also be included.

ELECTRICAL CLEARANCES
Maintaining adequate electrical clearances between the mobile equipment, its connections, and other equipment is of prime importance. Installation using bare conductors should not be considered for a location unless the minimum clearances listed in ANSI C37.32-1996 can be maintained. Insulated conductors can be used in some locations if the minimum clearances cannot be maintained.

ANSI C37.32-1996 identifies the minimums values that should be maintained or exceeded at all times. Phase-to-ground and phase-to-phase clearances should be coordinated to ensure that possible flashovers occur from phase to ground rather than from phase to phase.

The minimum metal-to-metal clearances should be maintained at all times with the switches in the open position, closed position, or anywhere between the open and closed positions.

In some locations, contamination from airborne particles necessitates increasing the minimum electrical clearances. Satisfactory operation can usually be obtained by using clearances one step above those normally used. In extremely contaminated locations, additional clearance may be required.

Since the dielectric strength of air-insulated equipment decreases with increasing altitude, the clearances listed in ANSI C37.32-1996 have to be modified for use at altitudes above 1000 meters (3300 feet).

In addition to the electrical clearances previously described, it is necessary to provide adequate space for equipment maintenance. In arrangements where equipment such as the power circuit breakers, reclosers, disconnect switches, power transformers, or other equipment has to be maintained while portions of adjacent equipment remain energized, provide sufficient space around the equipment to prevent accidental contact by maintenance personnel.

Depending on the nominal voltage of the equipment (disconnect switches, circuit switcher, surge arresters) and the dimensional constraints imposed by legislation, they may have to be located on a sliding, rotating or swiveling structure. These structures must be able to be manually operated by one or two persons without requiring excessive effort. These structures allow the mobile substation to comply with the limit width imposed by transit legislation while the vehicle is in transport, and at the same time allow compliance with required electrical clearances when the mobile substation is placed in service.

GROUND NETWORK
Adequate grounding of mobile transformers and substations is extremely important for safe operation. At least two independent connections should be made between the trailer and the ground system. The mobile equipment should be connected to the substation ground grid whenever it is close to the substation. In situations where the mobile is located a long distance from the substation and connection to the substation ground grid is impractical, a separate ground system has to be provided.

Rigid Conductors
Rigid electrical conductors are available in a variety of shapes and sizes to suit individual

requirements. Some of the more commonly used shapes include flat bars, structural shapes, and tubes. Specific physical and electrical properties and application data can be obtained from the conductor manufacturers.

Flat Bars

Flat bars can be utilized for outdoor substation buses and are particularly suitable since they can be easily bent and joined. For high-current applications, a number of flat bars can be grouped together, leaving a small space between the bars to facilitate heat dissipation.

The trailers must be provided with a General Ground Network, made from copper bar with 2 x 3/16 in cross section, fixed all around. All main parts of the metallic structures, and also the dead parts of the equipments should be connected to the Mobile Substation Grounding Network in copper bar. Provision shall be made for at least four (4) external points (2 front left & right and 2 rear left & right) to connect the trailer to the station ground system.

To ensure proper grounding connections, all components/accessories which are intended to be grounded, ground continuity shall be checked (pinned, flanged, painted, and flexible connections shall have external jumpers installed to ensure ground continuity.)

CIRCUIT BREAKERS

The application of circuit breakers involves consideration of the intended function, expected results, benefits to the electric system, and characteristics of both the circuit breakers and the electric system. In some instances, protective devices of lesser capability and flexibility, such as fuses, circuit switchers, reclosers, etc., may be more desirable or preferred over more complex and costly circuit breakers.

Writing of specifications and selection of power circuit breakers and similar devices should be preceded by electric system studies to determine the parameters of application and operation that have to be satisfied. These include load flow, short-circuit, transient voltage, coordination, and protection studies.

No general guidelines can be drawn for the application of these various types of circuit breakers. Each user has to determine the ratings of circuit breakers required and then select a type of circuit breaker acceptable with regard to rating, performance expectations, compatibility with planned or existing substation configuration, and the ability to install, operate, and maintain the circuit breaker. Cost may also be an important consideration in the final selection.

CIRCUIT SWITCHERS

Circuit switchers are less costly than circuit breakers and can be applied in much the same way as circuit breakers, subject to limitations in interrupting capability, with the same type of relay control as circuit breakers. Circuit switchers are also supplied without current transformers (circuit breakers are usually supplied with CTs), which are used in conjunction with relays to sense faults.

This detection would utilize relay intelligence from the low-voltage side. Circuit switchers also provide excellent capacitor bank switching and protection. In outlying areas of moderate short-circuit capacity; they can often be substituted for circuit breakers. They can be mounted similarly to air-break disconnect switches on a mobile substation sliding structure and thus require little or no additional space.

Minimum required information:

1. Type (3-phase, 1-phase, Auto):	
2. Rating (MVA):	
3. Primary Voltage (KV):	
4. Primary Regulation (DETC, OLTC):	
5. Primary Regulation tap range (%):	
6. Secondary Voltage (KV):	
7. Secondary Regulation (DETC, OLTC):	
8. Secondary Regulation tap range (%):	
9. Primary Winding BIL:	
10. Secondary Winding BIL:	
11. Insulation[2] (Nomex, cellulose, Hybrid):	
12. Impedance Limit:	
13. Bushing current transformers ratings:	

TRAILER
A mobile substation trailer must be capable of transporting substation equipment, meeting all applicable transportation legislations and best use practices.

Trailers shall be customized for each solution, and can be designed for high strength and to support rough conditions. Load calculations must be performed to accurately estimate axle and kingpin loadings and trailer design during proposal stage.

Customer shall define, prior to proposal submittal, the limits based on the constraints – state or local legislation - of the region where the unit will be displaced and/or the customer's limits (parking limits, turning radius, substation arrangement). Customer must inform the region where the unit will be transported to allow manufacturer's engineering department to contact the country/region transportation authority, like DOT or similar departments. Registration of the trailer is up to the customer.

MAXIMUM DIMENSIONS
According to the size of the equipment to transport it is necessary to verify the applicable legislation. It's necessary to verify if the equipment to be transported will meet the standard legislation or requires an over-dimension permit. The power transformer is the equipment that will have the most impact on the Mobile Substations dimensions. Since the weight limits imposed by US Federal legislation are normally quite restrictive, only mobile substations with lower MVA ratings and voltages will be able to move about without over- dimensional/overweight permits.

The customer must define the physical constraints to which the mobile substation must abide by:

1. Maximum Overall Length:

2. Maximum Overall Height:
3. Maximum Overall Width:
4. Minimum ground clearance:
5. Maximum Weight for:
    i. Tractor and trailer combination;
    ii. Trailer(s);
    iii. Axle or group of axles (indicating spacing between axles and axles groups);
    iv. King pin or towing eye;

Sometimes after the calculation is completed it is necessary to revise these limits since some of the equipment can't meet the constraints.

Additionally if the customer owns a tractor vehicle its characteristics (dimensions, weights, brand, model, etc.) should be indicated so that the mobile substation design can be optimized.

TRAILER FUNCTIONAL ACCESSORIES

Axles

The number and type of axles is determined according to the weight distribution and the desired maneuverability. The axles can be of the following types: fixed, self steerable or steerable. Normally the number of axles, number of tires and the maximum allowed load are the main factors to choose the axles configurations.

Tires and Wheels

The trailer normally uses a robust small diameter trailer tire, designed to withstand the demands of high scrub and spread axle service. The normally used tire sizes are: 17.5 inches. The choice of size is according with the application of the trailer and also with the interchangeability with other tires from an existent trailer fleet. Required information:

- Type and dimensions of tires/wheels