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## Articles and Statements

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**Articles and Statements**

# Voltage Quality Analysis of Small-Capacity Grid-Connected Photovoltaic Systems in Low Voltage Distribution Networks

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**Abstract**

At present, the demand for small-capacity grid-connected photovoltaic system is growing, because it reduces the cost of storage systems. The article focuses on analyzing the voltage quality of small-capacity grid-connected photovoltaic system in low voltage distribution networks at yard of Quang Tri Branch – Hue University, Viet Nam. The analysis proceeds over dark time, when the system consumes electricity, and over light time, when the system put electricity into the grid. Analysis results indicate that system parameters has match the requirements and the emergence of small-capacity grid-connected photovoltaic system contributes to improving the total harmonic distortions of low-voltage network.

**Keywords:** Total Harmonic Distortions, Voltage Quality, Grid Connected photovoltaic.

## 1. Introduction

Quang Tri Province, Vietnam has a relatively high number of sunshine hours, average 5-6 hours per day, relatively abundant radiation source, from 1471-1688 kWh/m$^2$/ year. Months with high sunshine are usually in May, June, August, and over 200 hours per month. The government has set out orientations for the development of solar energy, which is expected to generate 1.4 billion kWh (0.5 % of total electricity) by 2020, about 35.4 billion kWh (6 % of total electricity production) by 2030 (Decision, 2015). In our country, the demand for photovoltaic (PV) systems is becoming increasingly popular, the Circular 16/2017/TT-BCT "Regulations on project development and Power Purchase Agreement for Solar Power Projects" makes the market for solar electricity increasingly active (Circular, 2017).

Small-capacity grid-connected photovoltaic systems include PV panel, grid tie inverter. PV panel generates DC current, the inverter converts the DC current into AC at the same frequency to the grid.

The analysis of the output voltage of the inverter is very important, it ensures that the grid-connected system is allowed to connect to the national grid or not. According to the regulation of electricity distribution system of Vietnam in accordance with Circular No. 39/2015/TT-BCT (Circular, 2015), regulations on voltage of grid-connected photovoltaic system must meet the requirements in the Table 1.

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**Table 1.** Voltage requirements of grid-connected photovoltaic system

| № | Parameters | | Required value |
|---|---|---|---|
| 1 | Operating voltage | | 187-242V |
| 2 | Unbalanced voltage ($V_{unb}$) | | <5% |
| 3 | Voltage harmonics | THD | <=6,5% |
| | | Harmonic order 3 | H(3)<=3% |
| | | Harmonic order 5 | H(5)<=3% |
| | | Harmonic order 7 | H(7)<=3% |

Many studies have examined THD for the line-ground voltages $THD_V$ and line-line voltages $THD_U$, together with average values over the measured có time intervals in a working day, daytime and peak load time (Neagu, 2016), voltage raise, voltage flicker, and power factor reduction (Farhoodnea, 2013). The simulation results proved that the presence of 1.8-MW high-penetrated grid-connected PV systems in a radial 16-bus could cause power quality problems such as voltage raise, voltage flicker, and power factor reduction (Farhoodnea, 2013).

The paper (Pinto, 2015) presents a power quality analysis of two different facilities with PV generation localized in a rural area of Portugal, describing the voltage and frequency behavior, the harmonic contents, and the total harmonic distortion. Statistical data are presented regarding the number of voltage events and occurrence of dips and swells in both facilities as a percentage of rated voltage. The paper conclude that some PV systems can severely affect voltage quality, forcing the grid to work at and even above the maximum voltage standard limit.

The paper (Anwari, 2009) presents power quality analysis of a distributed generation system consisting of PV–Inverter system as the renewable source connected to a network of with adjustable speed drives load.

The analysis of the data shows trends in the harmonics behavior in the grid-connected PV system with adjustable speed drives as loads and can be used to analyze power quality in a system with similar components and setup. Worst case in this project was determined and identified when the system had to change the energy supply from PV to grid. At condition when system nearly changes the supply, current THD has the higher value. The best case happened when energy supply from PV is strongly used rather than grid (Anwari, 2009).

The power quality parameters of 10 kWp PV grid-connected system measured are the active and reactive power, the power factor and the total harmonic distortion. The analysis of the results shows that implementation of the PV grid-connected system could improve the power quality in distribution systems. the grid THD voltage lies in the range of 2-6 % which is acceptable. Unlike the current THD increases significantly at low PV generation conditions reaching a value of 60 % for the inverter and 90 % for the grid (Bouchakour, 2012).

The results in paper (Srisaen, Sangswang, 2006) have shown the PV installation location and a large number of the PV generation have affected the distribution system in a positive manner. The PV generation has shown much potential as a grid-support system which can be used to enhance the distribution operation and power quality including voltage profiles and system loss reduction.

The paper (Altarawneh, Alshawawreh, 2017) provides an experimental observation study of 2.1 kW grid-connected PV system connected to low voltage-grid, the power quality parameters at the inverter output side have been measured using Fluke 435- II Class A three phase energy and power quality analyzer, the voltage waveforms in general are combatable with the standard, with a THD ranging from 1- 3.2 % as an average values was about 1.25 %. The relation between voltage THD and the output power from PV shows that they are independent of each other.

The paper (Elkholy, 2016) presents a comprehensive evaluation of the performance of the system over a period of one week, measurements of the power quality parameters obtained from the PV site, results has shown the voltage THD of the system is not strongly dependent on the fluctuations of solar irradiance.

The paper (Megha, Kumar 2017) investigates the presence of voltage and current THD due to the linear, nonlinear loads and the reactive power transferred between plant, grid and load. The experimental results shown above depicts that due to the presence of voltage and current THD the power factor of the system gets affected and also the reactive power is highest in the presence of nonlinear load, which in turns affect the power flow in the system i.e. from plant to grid and grid to the load.

The project in papers (Cuong, Hong 2016; Cuong, 2016) has studied the improvement of output energy of PV system by tracker, the output energy increase likely affect the quality of the grid voltage, when PV system connected grid, this issue needs further study.

Above analysis show that, there is no study of voltage quality of grid-connected photovoltaic systems at dark time (when the system consumes electricity and does not put electricity to the grid) and at light time (when the system put electricity into the grid). So this article will present and evaluate the voltage quality of the small- capacity grid-connected photovoltaic systems in low voltage distribution networks such as: operating voltage, THD, operating frequency, unbalanced voltage in dark and light time.

## 2. The small-capacity grid-connected photovoltaic systems

Object of this research is grid-connected photovoltaic power systems (GPVPS). The major elements of a grid-connected PV system that does not include storage are shown in Figure 1.

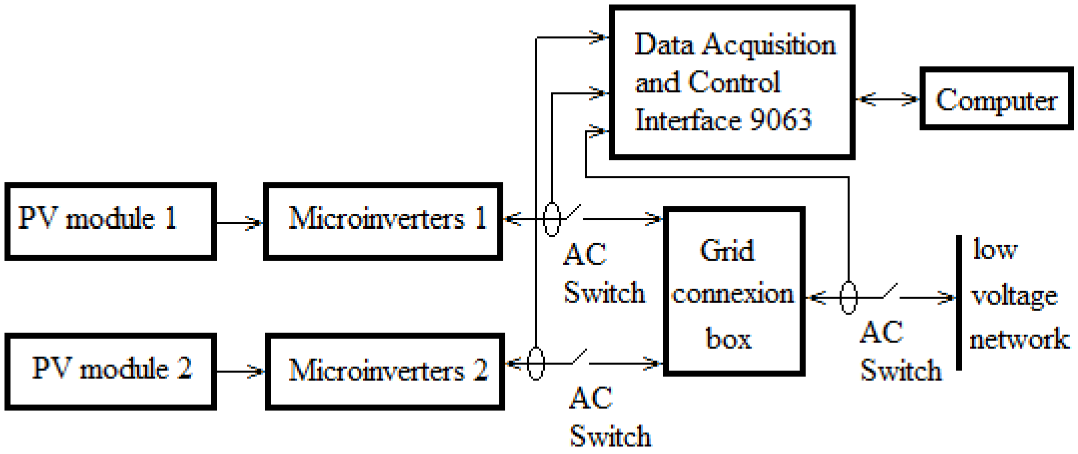


**Fig. 1.** Grid-connected PV system configuration

This research uses two similar grid-connected photovoltaic power systems, including a 250W PV panel and a 250W MPPT microinverter. Both of the PV modules were mono-crystalline based and the specification can be seen in Table 2. Table 3 shows parameters of microinverters.

**Table 2.** PV electrical specification

| Properties | Value |
|---|---|
| $P_{mp}$(W) | 250 |
| $V_{oc}$(V) | 37,4 |
| $I_{sc}$ (A) | 8,83 |
| $V_{mp}$ (V) | 30,0 |
| $I_{mp}$ (A) | 8,33 |

**Table 3.** Parameters of microinverters

| Properties | Value |
|---|---|
| $P_{mp}$(W) | 250 |
| $U_{in}$ (VDC) | 22-45 |
| $U_{out}$ (VAC) | 190-260 |
| Output frequency | 50/60 (auto) |
| TDH | <3% |
| Steady output efficiency | >90% |
| MPPT range (VDC) | 28-36 |
| Power factor | >97% |

The installation is located on the yard of Quang Tri Branch – Hue University, Viet Nam (latitude 16°N, longitude 107°E). The electricity produced by photovoltaic solar panels is injected directly into the Branch low voltage distribution networks without storage device.

The main measurement instrument is Data Acquisition and Control Interface. The Data Acquisition and Control Interface with the LVDAC-EMS software provide a complete set of modern computer-based instruments to measure, observe, analyze, and control electrical parameters such as voltmeters, ammeters, power meters, frequency meters, energy meters, an oscilloscope, a phasor analyzer and a harmonic analyzer.

## 3. Results and discussions

Results obtained with tests and voltage quality analysis performed on two grid-connected PV systems (GCPVS) and grid at point of common coupling (PCC). The measurements were made on 19 November 2018 with a sampling frequency of 1 min.

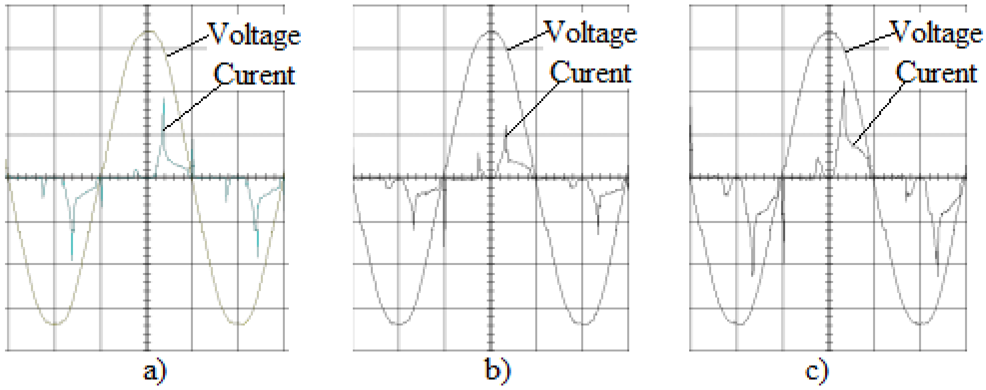


**Fig. 2.** Voltage and current at 7h42 with time base 5ms / div, voltage scale 100V/div, current scale 0.5A/div. a) GCPVS 1; b) GCPVS 2; c) grid at PCC

Figure 2 shows the voltage and current waveforms at 7h42. The current and voltage RMS value of GCPVS 1 are $U_1$ = 242.5V, $I_1$=0.18A. The current and voltage RMS value of GCPVS 2 are $U_2$=242.94V, $I_2$=0.14A. The current and voltage RMS value of grid at point of common coupling are $U_3$=242.73V, $I_3$=0.3A.

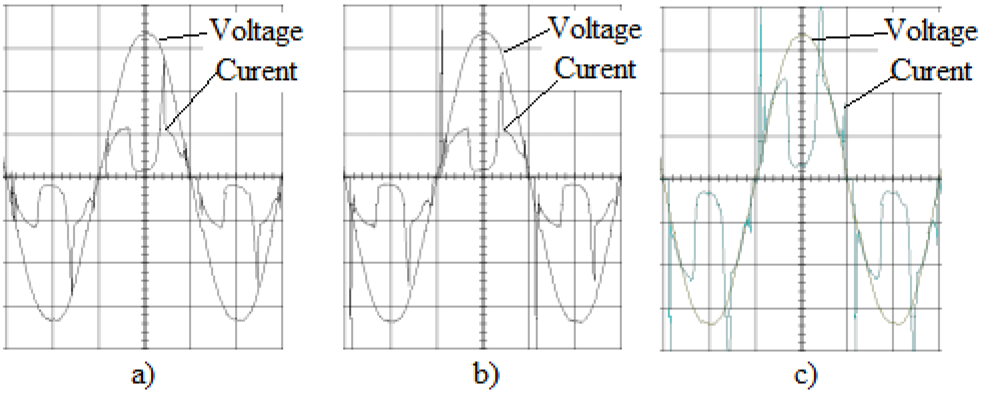


**Fig. 3.** Voltage and current at 13h31 with time base 5ms/div, voltage scale 100V/div, current scale 1A/div.
a) GCPVS 1; b) GCPVS 2; c) grid at PCC

Figure 3 shows the voltage and current waveforms at 13h31. The current and voltage RMS value of GCPVS 1 are $U_1$ = 240.52V, $I_1$=0.83A. The current and voltage RMS value of GCPVS 2 are $U_2$=241.12V, 0.9A. The current and voltage RMS value of grid at point of common coupling are $U_3$=240.83V, $I_3$=1.66A.

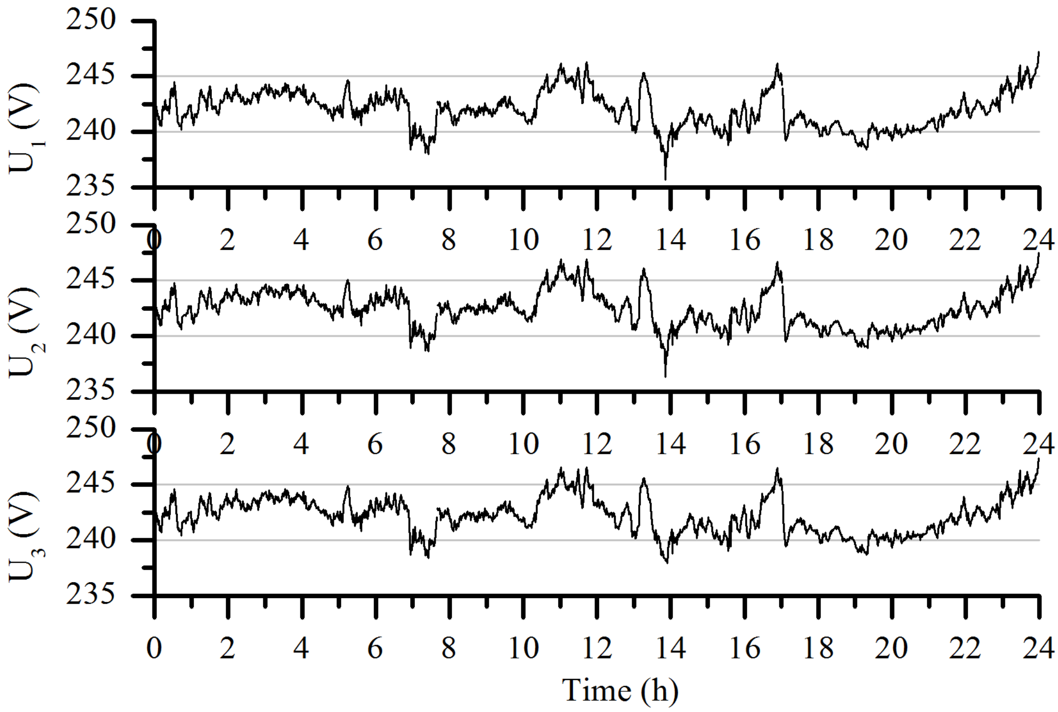


**Fig. 4.** Voltage values during the day ($U_1$ of GCPVS 1, $U_2$ of GCPVS 2, $U_3$ of grid at PCC)

Voltage values for time of day show on Figure 4. Figure 5 shows the voltage value analysis at dark time (when the system consumes electricity and does not put electricity to the grid) and at light time (when the system put electricity into the grid) for GCPVS 1, GCPVS 2 and grid at PCC in box plot form.

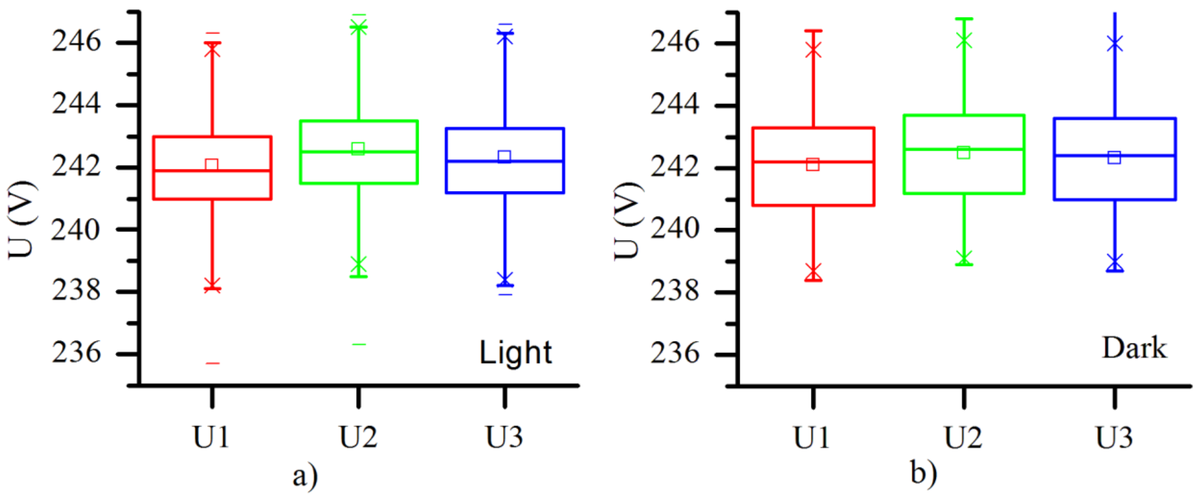


**Fig. 5.** Voltage box plot of GCPVS 1 ($U_1$), of GCPVS 2 ($U_2$), of grid at PCC ($U_3$).
a) In light time; b) In dark time

Specific results are given in Table 4. These results show that the unbalance voltage value is 1.64 % to 1.69 % at light time (when the GCPVS puts electricity into the grid). But the voltage points are too low such as 235.7V, 236.3V, 237.9V, these points correspond to the time 13h51' can be affected by the load of the system increased suddenly.

**Table 4.** Specific results of voltage values

| Voltage | | 1. Max outlier (V) | Max (V) | Average (V) | Min (V) | 1. Min Outlier (V) | $V_{unb}$ (%) |
|---|---|---|---|---|---|---|---|
| in light time | $U_1$ | 246.3 | 246.0 | 241.9 | 238.1 | 235.7 | 1,69 |
| | $U_2$ | 246.9 | 246.5 | 242.5 | 238.5 | 236.3 | 1,64 |
| | $U_3$ | 246.6 | 246.3 | 242.2 | 238.2 | 237.9 | 1,69 |
| in dark time | $U_1$ | 247.2 | 246.4 | 242.2 | 238.4 | | 1,73 |
| | $U_2$ | 247.5 | 246.8 | 242.6 | 238.9 | | 1,73 |
| | $U_3$ | | 247.4 | 242.4 | 238.7 | | 2,06 |

These results show that the unbalance voltage value is 1.64 to 1.69% at light time (when the GCPVS puts electricity into the grid). But the voltage points are too low such as 235.7V, 236.3V, 237.9V, these points correspond to the time 13h51'can be affected by the load of the system increased suddenly. Acceptable operating voltage on table 1 is 187-242V, but system maximum voltage about 246 V in light time and 247V in dark time. The lab low-voltage network is not full-load, this is the reason why system maximum voltage is larger than acceptable operating voltage.

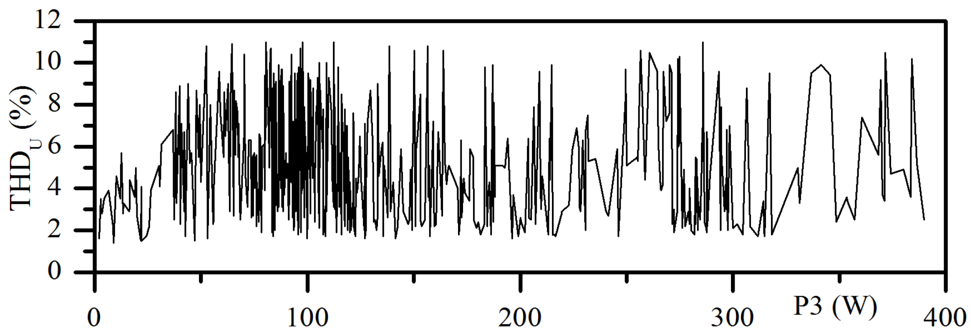


**Fig. 6.** Voltage THD as a function of two GCPVS output power

Figure 6 show voltage $THD_U$ as a function of two GCPVS output power. Results has shown the voltage THD of the system is not dependent on GCPVS output power.

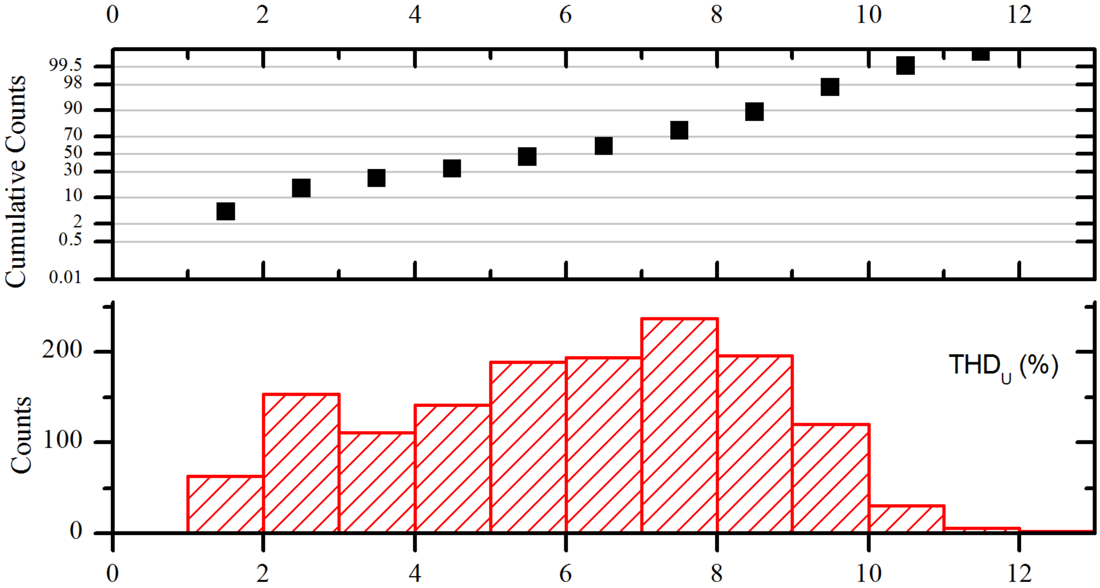


**Fig. 7.** Histogram representation of voltage THD values distribution during the day

Histogram representation of the voltage THD values distribution during the day given on Figure 7. Harmonics analysis is shown in Figure 8. It is clear that the odd harmonics affect the THD, the fifth harmonic (H5) is the largest.

Average voltage THD in light time about 4.7 % and average voltage THD in dark time about 6.5 %, that values are consistent with the acceptable voltage THD on table 1. Average voltage THD in light time less than average voltage THD in dark time, this proves that, the emergence of GCPVS contributes to improving the THD of lab low-voltage network.

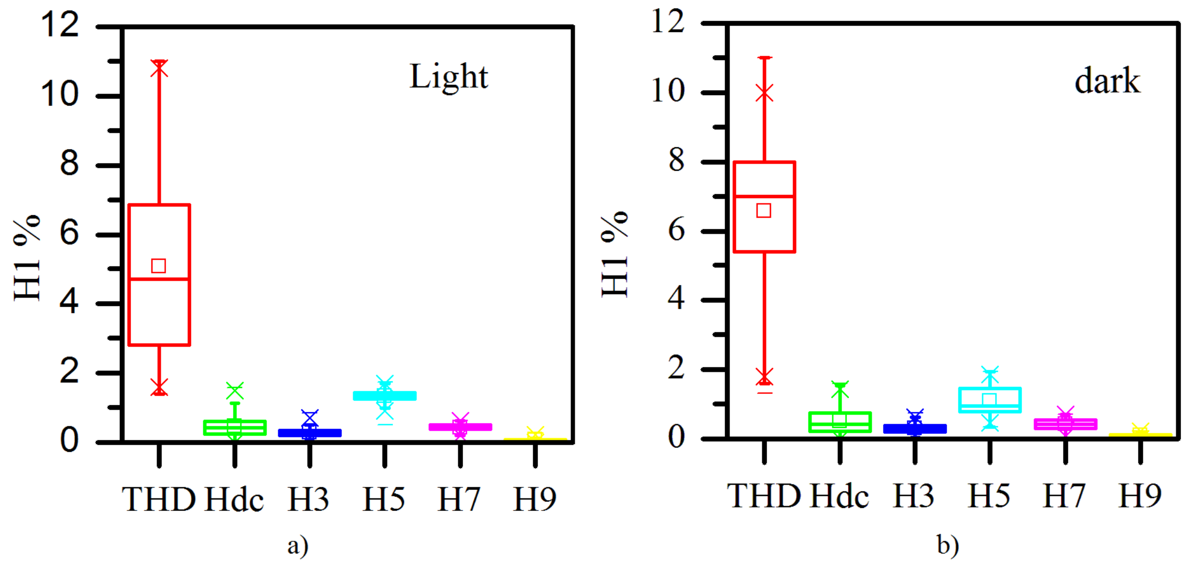


**Fig. 8.** Voltage THD box plot at Point of common coupling. a) In light time; b) In dark time

## 4. Conclusion

The paper presents the analysis of the voltage quality of small-capacity grid-connected photovoltaic systems at yard of Quang Tri Branch – Hue University, Viet Nam. The results indicate that the voltage THD and voltage values are within acceptable limits. Moreover the analysis of voltage THD shows the odd harmonics affect the THD, the fifth harmonic is the largest, the emergence of GCPVS contributes to improving the THD of lab low-voltage network.

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## Appraisal of Fire Protection and Coating for Buildings

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**Abstract**

For buildings and other constructions, fire protection is a must. The fear of uncontrolled fires and the desire to avoid their consequences is as ancient as human civilization. This fear has obvious enduring roots: unwanted fire is a destructive force that takes many thousands of human lives and destroys large quantities of asset. The primary objective of fire protection is to limit loss of properties and lives in the event of unexpected fires. Active fire protection is effective and efficient in most situations. However, passive fire protection, which includes the use of fire-proofing materials, provides an on-site fire resistance measure to prolong the longevity of load-bearing structures. Certainly, the nature, causes and scope of such events have changed considerably over millennia but fear and avoidance have remained as a primary human reaction and as an important human objective, respectively, for virtually every society. This paper will discuss on risk posed by fire, the passive fire protection components, conventional protection materials and thermally reactive materials. From the review, it can be concluded that Active fire protection is effective and efficient in most situations passive fire protection, which includes the use of fire-proofing materials, provides an on-site fire resistance measure to prolong the longevity of load-bearing structures.

**Keywords:** fire protection, active fire, fire resistance, construction, building.

## 1. Introduction

The fear of uncontrolled fires and the desire to avoid their consequences is as ancient as human civilization. This fear has obvious enduring roots: unwanted fire is a destructive force that takes many thousands of human lives and destroys large quantities of asset. Certainly, the nature, causes and scope of such events have changed considerably over millennia but fear and avoidance have remained as a primary human reaction and as an important human objective, respectively, for virtually every society (Vandersall, 1971). In the United Kingdom, for example, more than 400,000 fires occur every year in which about 800 people are killed and 15,000 sustain non-fatal injuries. Fires in the UK cost more than £1,000 million per year in direct fire damage. In addition, some fires cause indirect and consequential losses arising from loss of production, of profits, of employment and of exports and thus destroy a significant percentage of the economic wealth of a country.

To control the risk posed by fires, careful education and prevention is necessary but not enough, and fire protection measures have to be adopted. Fire protection involves the study of the behaviour, suppression and investigation of fire and related emergencies. It also includes research and development, production, testing and application of suitable fire protection systems (Taylor,

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1992). Fire protection system is an integral part of the building environment. The primary goal of fire protection is to limit the levels of fatal and non-fatal injuries, of property losses to be acceptable, in an unwanted fire event. There are two generic types of fire protection: active fire protection and passive fire protection.

Active fire protection commonly involves automatic devices and human direct actions to control and extinguish the fire. Although active fire protection is effective and efficient in most situations, some problems still remain (Shuklin et al., 2004). For example, an automatic sprinkler system, which sprays deluge agents over a local area under the activated sprinkler head, is a good form of active fire protection. However, a sprinkler system must operate early in a fire to be useful because the water supply system is designed to extinguish only a small size of fire (Purkiss, 1996). Similarly, fire-fighters can actively control or extinguish a fire, only if they arrive in time before it gets too large (Buchanan, 2001). Therefore, the most critical problems of using active fire protection are: (1) it needs time to respond, a very short delay will lead to hugely different consequences; (2) it relies on the supply systems, such as water, inert gas, foam. These conditions may not be met.

Passive fire-protection system is built as a part of the whole building. Not requiring operation by people or automatic controls, it can be considered as an on-site protector with instant response to fire. The primary reason for using passive fire protection is identical to that of all fire protection: life safety. This is mainly accomplished by maintaining structural integrity during the fire, and limiting the spread of fire and the effects thereof. While active fire protection aims to reduce life and property losses, passive fire protection design usually considers property protection as the secondary objective (Buchanan, 2001). According to the design requirements, in most cases passive fire-protection is used in conjunction with appropriate active systems, and it has been increasingly used and developed. By use of a suitable balanced protection system, the human and economic costs of fire damage can be significantly reduced (Anderson, Wauters, 1984).

## 2. Passive fire protection

Passive fire protection means insulating systems designed to deter heat transfer from a fire to the protected structures, or preventing combustion of flammable materials (Purkiss, 1996). For pre-flashover fires, passive control includes selection of suitable materials for building content and interior linings that do not support rapid flame spread in the growth period (Buchanan, 2001). In the fire protection literature, this aspect is referred to reaction to fire performance. In post-flashover fires, passive control is to provide, by using additional structures and assemblies, sufficient resistance to prevent fire spread through the building construction, which may occur as a result of excessive temperature rise, integrity failure (opening) or structural failure. Prevention of fire spread through the building construction is referred to as fire resistance. For example, walls and floors, structural steelwork and plant can all be protected either by the application of protective material to the substrate, or by the enclosure in a protection system (Buchanan, 2001).

There are numerous fire protection technologies currently available for protecting structural elements during a fire and providing sufficient fire resistance. These technologies use different methods to achieve their fire resistance ratings. Fireproofing materials range from conventional inorganic mineral based products to thermally reactive organic formulations.

## 3. Conventional protection materials

Application of insulating materials is one of the most common measures to protect the structure from direct fire exposure. The conventional materials, including concrete, brick, tile, and asbestos, have been quite prevalent because they perform well at elevated temperatures (Anderson et al., 1988).

In the past, mineral fiber asbestos was used with a cementitious binder and sprayed onto structural elements to provide fire protection. It was also combined with other materials to make asbestos board and asbestos wood. Due to proven health hazards associated with construction and occupancy periods, asbestos has been banned (Purkiss, 1996).

Gypsum (Figure 1) is a good and relatively inexpensive fireproofing material. It contains a high percentage of water that is chemically combined with the calcium sulfate (gypsum) base, and a large amount of energy is required to dehydrate and evaporate this water (Anna et al., 2002). It is typically attached to metal or wood framing, which is then attached to the structural member.

However, gypsum products have durability problem in corrosive environment and are subject to loss of integrity in long term service. Loss of water also adversely impacts the strength of the remaining gypsum board (Purkiss, 1996).

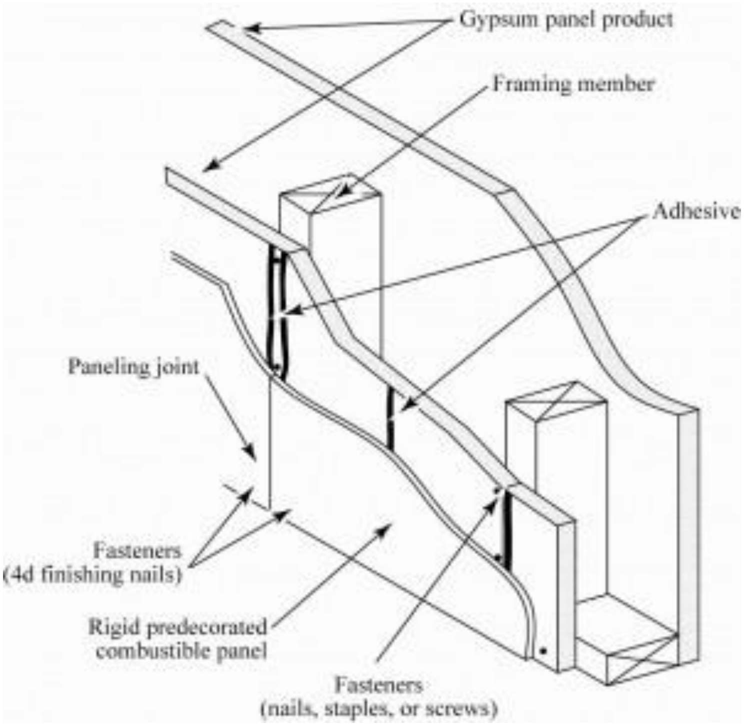


**Fig. 1.** Gypsum panel system

One of the more traditional methods of protecting structures involves encasing the steel member in concrete as shown in Figure 2. Similar to gypsum, concrete is an endothermic material which absorbs heat by evaporation of water content. Concrete is also a good thermal insulator with low thermal conductivity and high thermal capacity (Bourbigot et al., 2000). It therefore delays heat transmission to adjacent structural elements. Increasing the thickness of the concrete increases the time required for heat to transfer to the steel. A distinctive advantage of concrete is that this technology is well established and the required thickness of concrete to achieve sufficient fire resistance can be easily calculated (Buchanan, 2001). In addition, concrete has excellent durability in corrosive conditions. It performs well where resistance to impact, abrasion, weather exposure, and corrosive agents is important.

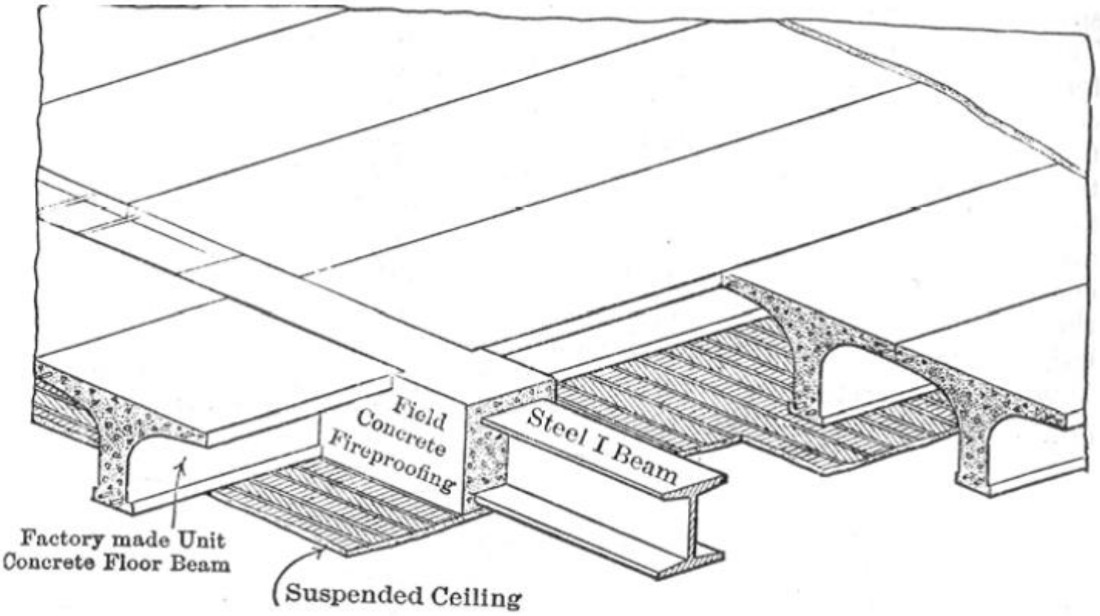


**Fig. 2.** Encasing the steel member in concrete

However, unless it is considered as a so-called “Steel Reinforcement”, concrete encasement has some notable disadvantages: poor aesthetic quality of concrete; concrete may take up valuable spaces around structural elements; concrete encasement is time consuming to install; concrete is heavy and can increase the overall weight of the building; transport and handling for off-site materials are difficult; concrete encasement is relatively expensive; concrete is susceptible to spalling (Branca, Di Blasi, 2002). These disadvantages can frequently limit the application of concrete encasement for protective purposes.

Spray applied fireproofing materials are typically cement-based products or gypsum with a light weight aggregate (vermiculite, perlite or expanded polystyrene beads) that have some cellulosic or glass fiber reinforcement as shown in Figure 3. Some of the earliest spray applied fireproofing materials contained asbestos, which is no longer allowed due to health issues (Buckmaster et al., 1986). This method is easy to protect detailed features including connections, bolts, etc. However, protecting on-site areas from overspray is typically required. Rough surface finish makes it not easy to meet aesthetic requirements. Intensive labor works are needed to adequately control quality.

**Fig. 3.** Spray applied fireproofing

Hollow structural elements can be filled in order to increase the heat capacity of the element, to act as a heat sink. Figure 4 shows an example of hollow slab. Typically, they are filled with either concrete or water (Buchanan, 2001). When filled elements are exposed to fire, the heat passes through the steel and begins to heat the fillings. This method allows use of exposed steel and does not increase thickness of the structural element. As the yield strength of the heated steel column is reduced, the load is transferred to the concrete fillings. However, this method significantly increases the weight of structural elements (Buchanan, 2001).

**Fig. 4.** Hollow slab

## 4. Thermally reactive materials

The conventional methods have some obvious drawbacks. These materials are heavy, lack of good appearances, hard to apply and need plenty of space. They are liable to shatter and spall when subject to fire. In addition, some of these products are with the potential hazards of mineral fibers.

The alternative is to use fire retarding coatings, which are one of the easiest, one of the oldest and one of the most efficient ways to protect a substrate against fire (Buckmaster et al., 1986).

Three major forms of thermally reactive materials are available, halogenated fire retardant coating, ablative/subliming coating and intumescent coating (Camino, 1988). Some years ago, the majority of the commercially used fireproofing materials were traditional halogenated fire retardants. These materials provide chemicals to act as flame poisons by interfering with the atmosphere immediately surrounding the coating, and hence inhibiting combustion (Taylor, 1992). These coatings have shown their highly effective performance. But on burning they generally evolve halogen acids and metal halides whose proven efficiency as fire retardants has to be balanced against their known potential effect in increasing the formation of obscuring, toxic and corrosive smokes (Buckmaster et al., 1986). In recent years, the use of these materials has been limited on account of the possible impact to the environment.

Ablative/subliming compounds are usually added to provide an additional layer for insulation. These coatings have active ingredients that absorb heat during exposure to a fire due to changing from the virgin solid coating into a gas phase. This action prevents heat transmission to the material that these coatings are applied to (Buchanan, 2001). The effectiveness of these compounds is a function of various elements including the coating material thickness, compounds' reactive temperature and enthalpy at thermal reaction, heat capacity of the substrate, and fire exposure. These coatings are similar to intumescent paints. However, the application procedure is complex and this results in relatively high costs for pplication. Furthermore, the fire depletes the protection compounds. Therefore once exposed, the protection provided by the compound is reduced or eliminated (Anna et al., 2002). This can be a major disadvantage during long fires that exceed the designed exposure period.

The above disadvantages associated with various types of passive fire protection materials have resulted in intumescent coating being increasingly favoured by architects and becoming dominant in the passive fire protection market in the UK.

## 5. Conclusion

In conclusion, it can be summarised that fire protection is essential for buildings and other constructions. The main goal of fire protection is to limit damage of properties and lives in the event of unforeseen fires. Active fire protection is effective and efficient in most situations. However, passive fire protection, which includes the use of fire-proofing materials, provides an on-site fire resistance measure to prolong the longevity of load-bearing structures. A broad selection of fire-proofing materials are available, however intumescent coating has become increasingly dominant in the fire protection market in recent years.

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# System Information

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**Abstract**

The article analyzes the system information as a particular type of information, describing complex systems. It is shown that system information can only exist in complex systems with the property of emergence. The work describes the basic formal descriptions of complex systems. This article describes the evolution of the linear description of complex systems. The article contains set-theoretical descriptions of complex systems. Descriptions of complex systems, including system information explicitly, have been obtained. The article provides insight into the contents of the system information. The article introduces the definition of system information.

**Keywords:** information, complex system, system approach, system description, system information.

## 1. Introduction

System information can be interpreted in different ways. The first concept. Systematized information, which has the properties of systematization and can be considered as a system. Information as a system is rather data system (Marz, 2015; Naghshtabrizi, 2008), although there are continuous discussions on the difference and similarity between "data" and "information" concepts (Pras, 2002). The second concept. Information, which describes the system signs (Kaleem, 2012; Cohen, 2016). The third concept. Information, describing a complex system (Johnson, 2006; Funtowicz, 1994). The fourth concept. Information, which creates the property of emergence in a complex system (Damper, 2000; Steed, 2012). Let's focus on the last variant: system information as characteristic of systematization and emergence of a complex system.

## 2. Materials and Methods

Numerous papers on system analysis, emergence and general systems theory have been used as materials. System and phenomenological analyses have been used as methods.

### Formal Description of Complex Systems

In many descriptions of complex system (Funtowicz, 1994; Hall, 1956; Bar-Yam, 1997), there in no place for information, especially for system information. The simplest description of complex system includes the structure of the system, elements and relations.

$$SYS = \langle Pr, Str, E, C, R \rangle, \quad (1)$$

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where (1) *Pr* – combination of parts of the system. *Str* – system structure. *E* – set of elements in the system; *C* – set of links in the system. *R* – set of relations between elements, parts and subsystems. This definition indicates, that the system is composed of different-type parts and has a structure.

When moving from an abstract complex system (*SYS*) to the application system (*AS*), it is required to include the existence of a goal. In this definition let's add to the already considered list (1) the set of goals (*G*). In this case, the application goal-defined system has the following description:

$$AS = \langle Ps, Pr, Str, E, C, R, G \rangle, (2)$$

*Ps* – set of subsystems; *G* – set of goals, and all other parameters are the same as in (1). Expression (2) characterizes the goal-defined system. Alternative goal-defined systems are comprehensive multipurpose systems.

If to include the inputs and outputs into the description, then we will get open system description.

$$AS = \langle Ps, Pr, Str, E, C, R, G, int, out \rangle, (3)$$

where *int* – set of inputs, *out* – set of outputs of the system. Availability of inputs and outputs of the system separates the system from the environment and allows to simulate the informational and physical interaction of the system with the environment. The boundaries of interactive system with many inputs and outputs are, in many cases, rather difficult to be defined. As a criterion, allowing to define those boundaries, force of relations between elements may be selected. This allows to separate from the system the internal elements and boundary elements. Boundary elements define the boundaries of the system. A system exists only when the force of relations between elements is stronger than the force of relations with the environment. In some cases, the concepts "closed" (2) and "open" (3) system are used, implying the presence or absence of relations with the environment. Closed systems can be considered as some abstraction, used for local research purposes.

In a number of targets, the time of performance of operations in the system or by the system is very important. The functioning of the system occurs within a certain range of time – interval (ΔT). In this case, the processes, occurring in the system and in the environment, are considered, and the dynamics of the system functioning is taken into account. These concepts are not used for abstract complex system. It appears for the application system (*AS*). In this case, description (3) should be supplemented by parameter $\Delta T$ – time of operational response of the application system:

$$AS(t) = \langle Ps, Pr, Str, E, C, R, G, int, out, \Delta T \rangle, (4)$$

Inclusion of the cognitive factor *Cog* in the system generates a human-machine system (*HMS*), which can be described as follows:

$$HMS = \langle Ps, Pr, Str, E, C, R, G, int, out, \Delta T, Cog \rangle, (5)$$

Expression (5) describes a model of the system and shows that *HMS* is the evolution and complexity of a complex system. Complex objects, such as company, public authority, public fund, etc, are often used as *HMS*.

The dynamic system *DS(t)* is characterized by changing of some parameters after a while and inclusion of time as an argument

$$DS(t) = \langle Ps, Pr(t), Str(t), E, C(t), R(t), G(t), int, out, \Delta T \rangle, (6)$$

Proceeding from the fact, that the system has the property of emergence, it cannot be studied only on the basis of an analysis of its parts or components. Study of the system only by the decomposition method, i.e. the method of decomposition of an integer into parts, is not sufficient, because it is limited to study of only parts thereof. An emergent system (*ES*) can be described by using the following expression

$$ES(t) = \langle Ps, Pr(t), Str(t), E, C(t), R(t), G(t), int, out, \Delta T, SI[E, C(t), R(t), t] \rangle, (7)$$

Where *SI* - system information. It occurs in the presence of nonlinear combination of system components and characterizes the emergence of the system. During decomposition of the system into parts, the system information disappears.

Expressions (1-7) are linear descriptions and allow subsequent modifications. For example, sometimes the goals are divided into external and internal goals or into goals of functioning and development.

$$G(t) \rightarrow G(t)int + G(t)out$$

Resources of the system, which define its life cycle, can be included into descriptions (2-7). System status, which is divided into internal and external statuses, can be included into descriptions (2-7). In case of description of a system in an external environment, it comes to the concept of information situation as micro-environment, which significantly interacts with the system.

All considered descriptions of complex systems (1-7) refer to the linear descriptions. The principle of formulation of expressions (1-7) is linear. In case of occurrence of a new property or feature of the system, it is denoted by ID and included into the set (1-7) describing a complex system. The fundamental thing in the analysis of descriptions of complex systems is the identification of system information as an explicit factor in the expression (7).

There are more complex descriptions of systems. They include not one, but several expressions, which describe a complex system. For example, let's consider the approach of Mesarovich and Takahara (Mesarovic, 1960, Mesarovic, 1975, Mesarovic, 2000), who introduce the concept of system theory at the set-theoretical level.

The peculiarity of the approach in the work is the introduction of auxiliary objects, which are called state objects. The elements of these objects are called the system states. In information interpretation of these concepts, they can be compared to the information situation and information position. Relation on non-empty sets is called common system.

$$S \subset \otimes \{Vi \,;\, i \in I\} \quad (8)$$

where ⊗ - symbol of Cartesian product, and *I* – set of indexes. Set *Vj* is called the system object. If the set, of course, then (8) it takes the following form

$$S \subset V1 \otimes V2 \otimes \quad \otimes Vn \quad (9)$$

An example of such system is the Cartesian coordinate system (*CS*)

$$CS \subset X \otimes Y \otimes Z$$

Mesarovich introduces the concepts of input set (I*x*) and output set (I*y*), which is much wider than the concepts of input and output.

$$Ix \subset I;\ Iy \subset I;\ Ix \cap Iy = \varnothing;\ Ix \cup Iy = I;$$

Set $X = \otimes \{Vi \,;\, i \in Ix\}$ is called the input object, and set $= \otimes \{Vi \,;\, i \in Ix\}$ is called the output object of the system. These are basically input and output sets. In this case, *S* is defined by the following relation

$$S \subset X \otimes Y \ (10)$$

If *S* is a function, then the expression (10) is transformed into the functional relation

$$S: X \rightarrow Y \ (11)$$

In case of the description according to (11), the system is called functional. This approach is used in the stratification of the systems. However, it should be noted that in this approach and description there was no pace for the features of emergence and system information.

Despite the widespread use of approach of Mesarovich and Takahara, in their theory there are also some problems. There is no concept of composition and syntactics.

Let's consider the approach to the system theory of Yu.A. Urmantsev. He introduced the concept of the law of composition into a system definition in 1968. This allows to consider the system as an ordered set of objects. It introduced the concepts of "object" and "object-system".

Object *is* any material or ideal object of thought, as well as properties and relations: quantity and quality, preservation and change, essence and phenomenon.

Object-system is uniformity, built by relations of set {R}, laws of composition, set {Z} out of "primary" elements of set {M*)}*, selected on the basis of set *{A)}* out of the universe *U*.

The method of integration, which allows to synthesize the integer out of the elements of the system, applies for the object-system. Such approach provides for formation of the whole picture of the system and its comprehensive system analysis.

Subject to the approach of Yu.A. Urmantsev (Urmantsev, 2017), construction of abstract complex system includes the stages.

I. Selection from the universe *U* and primary set *M* by a single base $Ai^{(0)}$ of some set of elements $Mi^{(0)}$ – hereinafter referred to as the set of primary elements. In the theory of measurement, it is called the information collection.

II. Imposition on the primary elements of certain relations of uniformity $Ri^{(0)}$ and as a result on the formation of the set of compositions $Mi^{(1)}$ under the law $Zi^{(0)}$. Relations of uniformity create a coherent combination and system property of system integrity.

III. Changing of compositions of set $Mi^{(1)}$ according to the relations ($Ri^{(2)}$, $Ri^{(3)}$,. . . $Ri^{(s+1)}$) and the laws of composition ($Zi^{(2)}$, $Zi^{(3)}$, $Zi^{(4)}$, . . . $Zi^{(s+1)}$ and such derivation of sets of compositions ($Mi^{(2)}$, $Mi^{(3)}$, . . . $Mi^{(4)}$, $Mi^{(s+1)}$), whereby the compositions of all these sets turn out to be built out of primary elements of the same set $Mi^{(0)}$.

IV. Joining of all objects of the set *Mi* possible for *Ai , Ri , Zi* , in the form of unified system *Si , = Mi = {* $Mi^{(0)}$, $Mi^{(1)}$, . . . $Mi^{(s+1)}$, *}*.

Urmantsev gives the following definition of an abstract system. System *S* is the *i-th* set of compositions *Mi*, built on relations *rj* of the set of relations *{R;}*, the laws of compositions z*j* of the set of laws of compositions *{Zi,}* out of primary elements $k^s$ of the set, selected on the basis of $Ai^{(0)}$ out of set *M*. Primary elements $k^s$ in the theory of information technologies are called the information units.

However, this definition has no place for system information and even relations. Therefore, let's develop this definition more completely.

System *S* is the set of compositions *Mi*, built for relations of the set of relations {R*i*}, the laws of the set of laws of compositions {Z*i*,} which contains the set of links {C*i*}, uses the set of reasons {$Ai^{(0)}$} for the building, and contains emergent (system) information {EI*i* }.

Therefore, according to this definition, in order to form the complex emergent system, the following rules (1-6) are to be performed:

1) select some base $Ai^{(0)}$, and based on it select the set of primary elements $Mi^{(0)}$;
2) impose on it the relations of uniformity of the set {R*i*},
3) subject these relations and related operations to the laws of the composition of set {Z*i*};
4) fix the connections {C*i*}
5) extract the emergent (system) information {EI*i* };
6) receive system S*i*.

System *Si* is heterogeneous and has the structural type (a-f):

a) *Si* = { $Mi^{(0)}$, $Mi^{(1)}$, . . . $Mi^{(s+1)}$}, components
b) *{ Ai }* ={ $Ai^{(0)}$ , $RAi^{(1)}$ , $Ai^{(2)}$, . . . $Ai^{(s+1)}$ } information units
c) {*Ci*}= { $Ci^{(0)}$, $Ci^{(1)}$, . . . $Ci^{(s+1)}$} connections
d) {*Ri*},= { $Ri^{(0)}$ $Ri^{(1)}$ $Ri^{(2)}$, . . . $Ri^{(s+1)}$ } relations
e) {*Zi*,}= { $Zi^{(0)}$, $Zi^{(1)}$, $Zi^{(2)}$, . . . $Zi^{(s+1)}$} composition rules
f) {*EIi*} = { $IMZi^{(s+1)}$, $IAZi^{(s+1)}$, $ICi^{(s+1)}$, $IRi^{(s+1)}$, $IZi^{(s+1}$ } system information

This description of the system includes the rules of composition as the rules of system building (syntactics). This description of the system includes the emergent information. Not every system is built according to certain rules (1-6). Not every system has a structural type corresponding to items (a-f). But only systems, which are built according to rules (1-6), have the property of emergence and system information.

Let's define the system information as a nonlinear form of description of the properties of the system, caused by non-linear combination of relations of uniformity, connections, structure and rules of composition in this system. System information is the content of emergence property.

## 3. Discussion

System information is defined upon certain approaches and methods of descriptions of the complex system. System information describes the system properties. However, it cannot be equated with the terms of the system building. System information appears explicitly in complex system descriptions. For linear descriptions this is the expression (7) and its modifications. For set-theoretical descriptions, these are the rules (1-6) and structure (a-f). Explicit form or set of forms of description of system information is beyond the scope of this study. The analysis, performed in this work, shows only the method for defining system information.

## 4. Conclusion

Development of systems analysis and systems theory arrived at the need for introduction of the concept of system information and simulation of emergence. This is partly due to the success in the fields of study of developing and self-organizing systems. This is dictated by the requirements of artificial intelligence, which also needs the introduction of the concept of emergence and simulation of emergence, as well as introduction of concepts of system information as a non-linear phenomenon, defining the system properties.

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