EE

Application of EVI and GDI in Electronic Equipment

V.V. Krivtsov, V.I. Gurevich

An Optimization Method for the Serially Conected Electronic Components

An optimization method for a series DC circuitry is described. A practical calculation example is given to support the suggested theory.

In many applications of electrical and power engineering, namely in control and protection system design of high voltage equipment one often runs into problem of switching (commuting) relatively high voltages over relatively short periods of time. To have a few examples, one could consider the requirements for the protection system of powerful on-board transmitter that suggest switching 10 kV voltage for 100 µs or the control system of the communication amplifier high-voltage power source, which should be able to shutdown the latter in less than 1 ms.

Mechanical switching devices, such as oil, air and vacuum breakers, which can easily handle any voltages between 5 and 100 kV have a significant disadvantage: their operating time is as low as hundreds of milliseconds. Alternatively, solid state switching devices whose operating time does not exceed 1 ms, have limited capabilities in terms of operating voltage. While modern types of thyristors can withstand up to 1-2 kv, the maximum collector voltage for transistors ranges from 0.7 kV («Semirkon», FRG) to 1.4 kV («Mitsubishi», Japan), which essentially establishes the commutation limit, as far as DC circuitry is concerned.

One of the commonly practiced ways to increase the voltage capability of discrete devices is to put them in series. Leaving alone typical electrical problems associated with series connected components (such as voltage distribution in stationary and dynamic regimes), we will consider a reliability optimization problem.

Interestingly enough many investigators associate a shared load system only with a parallel system whose units equally share the system function. Incidently a series connected system of electrical elements having finite resistance also represents a shared load system with respect to overall voltage applied to the chain. The load-per-unit ratio (LPU) - in this case: voltage drop across a component - will be the same[1] for each element and inversely proportional to their number:

$$LPU = K_v = V_{ov}/(V_c N) = V'N^{-1}, \qquad (1)$$

where

V_{ov} = the overall voltage, applied to the system (which in many practical instances is associated with the voltage of a power source);

V_c = rated voltage of a system component;

V' = V_{ov}/V_c .

If a major failure mode for a particular type of component is short-circuit, then the series share load system will be basically no different from a parallel one, and the same model for the system reliability, which in the case of two units looks like

$$R_s(t) = [R_h(t)]^2 + 2\int_0^t f_h(t_1)R_h(t_1)R_f(t-t_1)dt_1 ,$$

where $f_f(t), f_h(t), R_f(t), R_h(t)$ = pdf's and reliability

[1] assuming equal resistances for individual components, and neglecting deviations owing to technological reasons

· functions for the full-load operation and half-load operation, respectively,

will hold. However, if the main failure mode is open-circuit, then the above equation becomes no longer valid, as $f_h(t)$ can not be defined (notably, $f_f(t)$ takes a form of the extreme value distribution in this case).

While in parallel shared load system the number of components that share the system's function effect the system reliability in a directly proportional way (the more components - the higher the reliability), their role in a series shared load system (SSLS) becomes double-entendre. On the one hand, one is interested in increasing number N, as it, in compliance with (1), diminishes the LPU and, according to the inverse power relationship or even simple life-stress considerations, increases component reliability. Fig.1 shows SSLS component reliability versus their number. On the other hand, SSLS is effectively a series system whose reliability depends on the number of components in an inversely proportional manner (see fig. 2). By analyzing the two figures, it becomes obvious that there exists a compromise in terms of N.

Therefore, the problem is to determine such an optimal number of elements in series which provides the highest possible reliability for both a single component and SSLS in whole. In other words, we are looking for the situation when the decrease in system's reliability will be compensated by the increase of the component's reliability

$$|\Delta R'| = |\Delta R''|,$$

here:

$|\Delta R'|$ = scaler change of the SSLS reliability, caused by the LPU reduction;

$|\Delta R''|$ = scaler change of the SSLS reliability, caused by the increased number of elements in series.

Since we are speaking about the LPUs being less than one, this problem can theoretically be interpreted as a problem of hot standby. However, we choose to proceed with the concept of SSLS, as the term 'series standby' seems to be contradictory in its essence.

Although it has been mentioned that the only relevant to the present discussion failure mode of the SSLS is open circuit, completeness wise it is probably worth allowing for the other mode too. The system reliability model in this case can be written in form of (2):

$$R_s = 1 - P_{sh}^n + (1 - P_o)^n, \qquad (2)$$

where P_o, P_{sh} = probability of failure due to open-circuit and short-circuit, respectively.

It is obvious that the SSLS model that accounts for only one failure mode is a particular case of (2) with P_{sh} being equal to one.

The component reliability is assumed to be distributed exponentially, as this is often the case for many technical applications in general, and electrical components - in particular.

Ignoring the burn-in period and assuming $d\lambda/dt$ = const, one can say that the failure rate of a single component depends on the application stress factor (which in our interpretation is expressed by (1)) and the ambient temperature (T). The generic version is:

$$\lambda_c = \lambda_b \Pi_A \Pi_Q \Pi_E \ldots \qquad (3)$$

where λ_b is the base failure rate, related to temperature and $\Pi_A, \Pi_Q, \Pi_E, \ldots$ are factors that take account of application stress, component quality level, equipment environment, etc.

For the convenience of our case it is better to represent (3) in another popular (Bardin-1978, Petuhov - 1988) form:

$$\lambda_c = (\lambda_b/AA')\exp(B\,K_v + B'T), \qquad (4)$$

here:

A,B,A',B' = empiric factors, defining the relationships $\lambda_b = f(K_v)$ and $\lambda_b = f(T)$, respectively.

Particular values of the factors are normally available from technical hand-books; if not - they can be easily obtained by methods of statistical testing.

To simplify the analysis further and keeping in mind that the failure rate as a function of temperature is now not of interest, we can transform (4) into :

$$\lambda_c = (\lambda/A)\exp(B\ K_v), \qquad (5)$$

where
$\lambda = (\lambda_b'/A)\exp(B'T)$.

Thus, the reliability function of SSLS, accounting for (1),(2) and (5), becomes:

$$R_s = \exp[-(\lambda tN\ /A)\exp(BV'/N)] - [1-\exp[-\lambda t/A\ \exp(BV'/N)]]^N, \qquad (6)$$

here t stands for time.

Figures 3 and 4 exhibit the system's behavior for the case of one failure mode and with power-source-to-component voltage ratio being equal to, and greater than 1, respectively. Similarly, figures 5 and 6 describe the case of two failure modes. All four graphs explicitly evidence the existence of optimal N that maximizes the reliability function of SSLS.

Denoting the first term of (6) as R_{so}, we will at first find the optimum N for the SSLS, having one failure mode (namely, we assume that the increase of LPU causes the open-circuit of a component). By solving

$$\partial(R_{so})/\partial N = [\exp(-(\lambda tN\ /A)\exp(BV'/N))]\,[(\lambda t/A)\exp(BV'/N))]\,[(BV'/N) - 1] = 0$$

with respect to N, optimum value of N is obtained:

$$N_{opt} = B\ V' \qquad (7)$$

Computing N_{opt} for the SSLS that has two failure modes becomes much more involved, as the derivative of (6) takes a non-trivial form:

$$\partial(R_s)/\partial N = [\exp(-(\lambda tN\ /A)\exp(BV'/N))]\,[\exp(BV'/N) - N^{-1}\exp(BV'/N)] + [\lambda t/(NA)]\,[\exp(-\lambda/A+\exp(BV'/N))\exp(BV'/N)] * [1-\exp(-\lambda t/A\exp(BV'/N))]^{N-1}$$

Although after a number of consecutive transformations it can be reduced to

$$\partial(R_s)/\partial N = X\ Y, \qquad (8)$$

where

$$X = [\lambda t/(NA)]\ [\exp((1-\lambda t/A)BV'/N)],$$

$$Y = [N-1]\ \ [\exp(-\lambda t/A\exp(BV'/N)(N-1))]\ [1-\exp(-\lambda t/A\exp(BV'/N))]$$

it is still impossible to resolve (8) explicitly with respect to N.

One can define the condition of extrema existence in the form:

$$\mathrm{Lim}_{N\to N_{opt}} \left|\partial(R_s)/\partial N\right| \to \min \qquad (9)$$

Analysis of (8) from the stand point of (9) has shown that while Y is a monotonous function of N, X - is not! It implies that it is X that makes (9) possible. As such, by differentiating X with respect to N, and equating the function obtained to zero, we come up with the expression for N_{opt}:

$$N_{opt} = B\ V'(1 + A^{-1}\lambda t) \qquad (10)$$

It is interesting to observe that (10) looks very much like (7), except for the quantity in parentheses.

Let us consider a thyristor switching device, operating in a stationary regime. The failure rate of thyristors as a function of overstress rate can be approximated (Petuhov-1988) by

$$\lambda = (\lambda_b/8.196)\exp(2.179K_v).$$

If we pick a thyristor of T-132-25-18 type (which shows λ_b= 1.6 10^{-6} hr^{-1}) and assume that the power source voltage exceeds the rated voltage of the thyristor by a factor of 5, than in accordance to (10) their optimum number for a mission of 10^5 hours will amount to

$$N_{opt} = 5 * 2.179\ (1 + (1.6\ 10^{-6} * 10^5/8.196)) \approx 11.$$

Analysis of a Series Shared Load System shows that:

The optimum number of components for a SSLS, major failure mode of which is open-circuit, is completely defined by power-source-to-component voltage ratio and the exponential term in a generic relationship, describing the failure rate model of the component under consideration;

If a SSLS component is characterized by both open-circuit and short-circuit failure modes, than the optimum number of components gets modified by the factor that involves the linear term of the mentioned relationship along with the base failure rate and mission time - as shown by (10);

As one can see from fig. 4 and 6, for practical applications it is preferable to keep the power-source-to-component voltage ratio as low as possible, since it drastically decreases the reliability of the system.

REFERENCES

1. A.N. Shirokov. *Fundamentals of Reliability and Maintainability of Electronic Equipment.* - Minsk: Science and Technology, 1975. -175 p.

2. I. Bazovsky. *Reliability. Theory and Practice.* - Moscow: Mir, 1965 - 373 p.

3. B.S. Sotskov. *Reliability Fundamentals of Theory and Design of Automation and Computation Equipment.* - Moscow: Higher Education, 1970. - 270 p.

4. V.M. Bardin *Reliability of Power Electronic Devices*. - Moscow: Energiya, 1978. - 96 p.

5. A. M. Grigoriev, E.F. Pogasy. *Estimation of Operational Reliability for Power Electronic Elements* // VEI Transactions, 1980, # 90. - p. 125-134.

6. A. M. Grigoriev, O.V. Baranchikova. *Effect of the Statistical Noise of Power Electronic Elements on their Reliability* // VEI Transactions, 1980, # 90. - p. 135-144.

7. V.Ya. Zamyatin, B.V. Kondratiev, V.M. Petuhov *Solid State Devices For Power Electronics. Thyristors*. - Moscow: Radio and Communication, 1988. - 576 p.

8. V.I. Gurevich, P.I. Savchenko. *Reliability of Hercotrones and Hercotrone Based Control Systems.* Optimization of Operational Control for the Agricultural Equipment - Moscow, 1982. - p. 78-79.

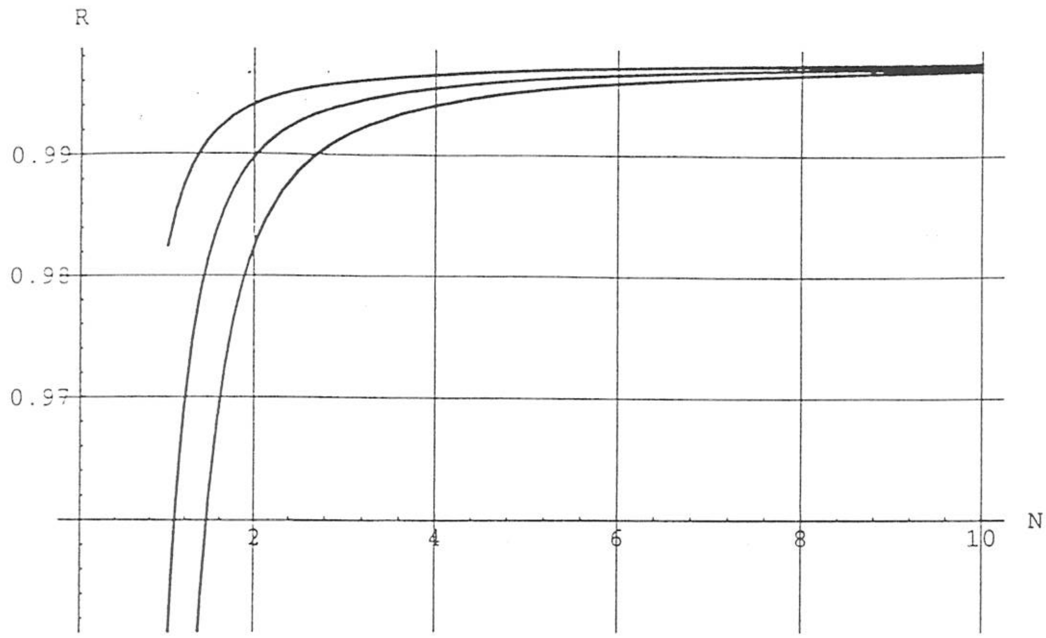

Fig. 1. SSLS component reliability vs. the number of components (top-down V' = 1, 1.5, 2).

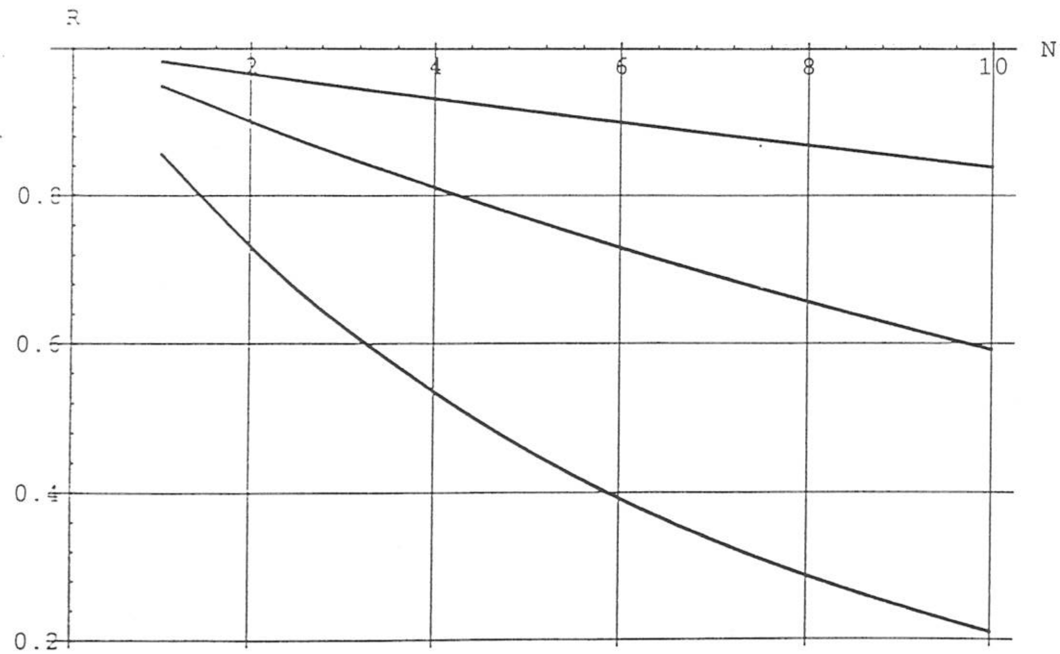

Fig. 2. SSLS system reliability vs. the number of components (top-down V' = 1, 1.5, 2).

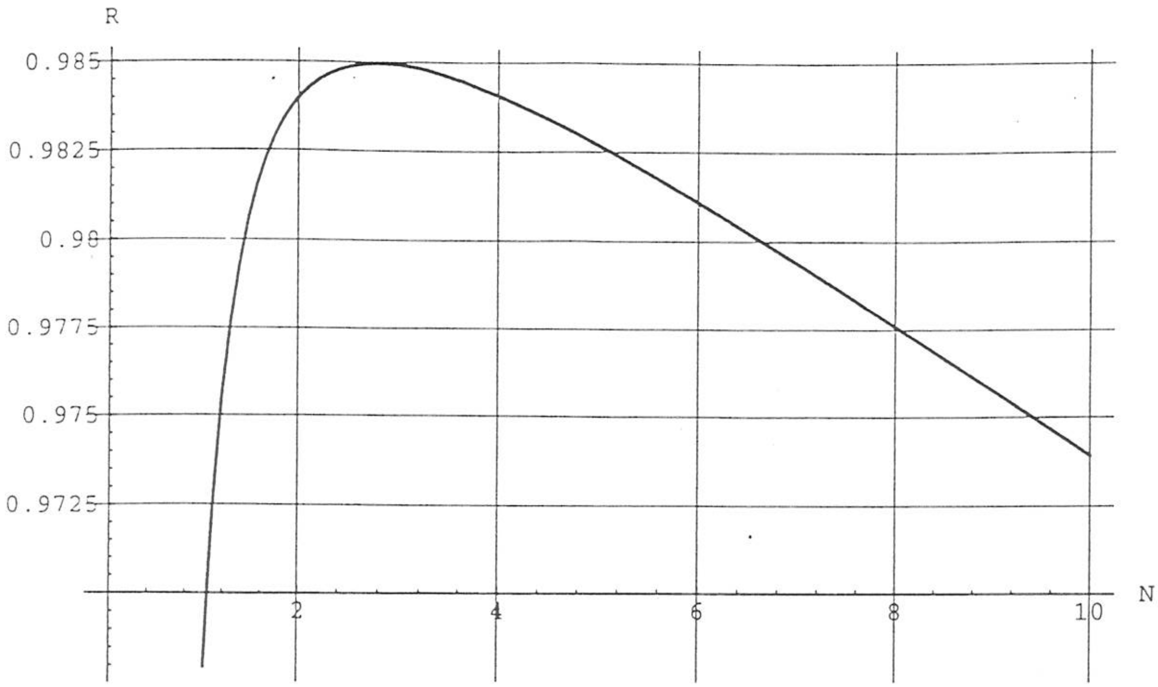

Fig. 3. SSLS reliability vs. the number of components, assuming one failure mode (V' = 1).

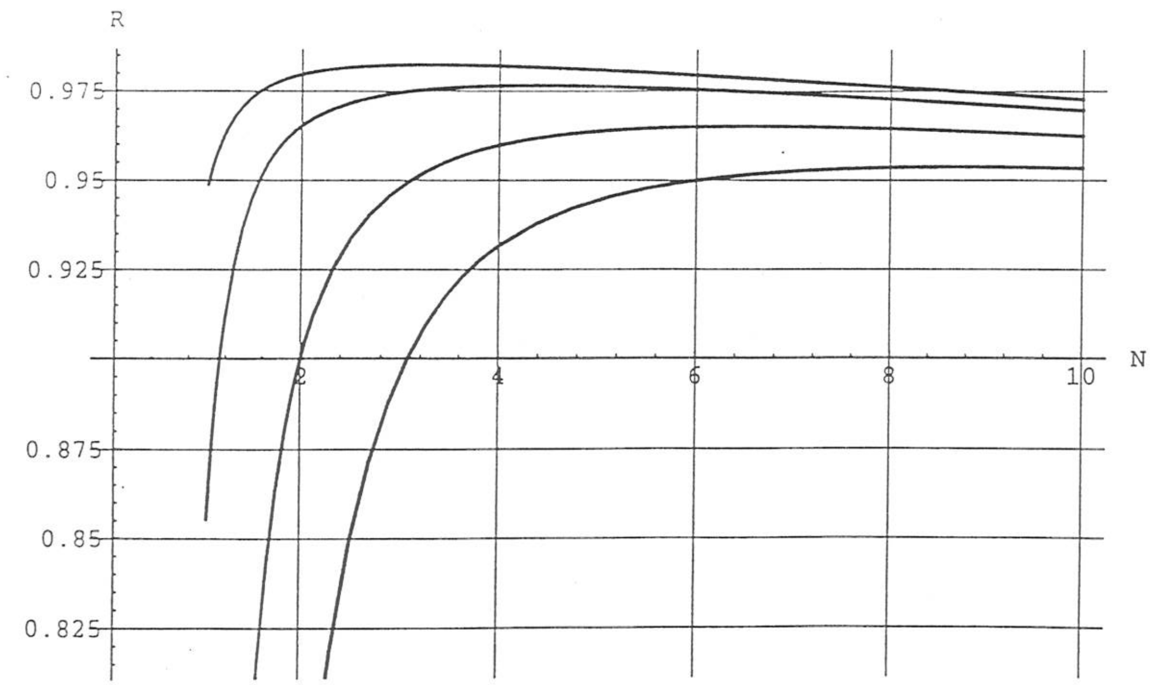

Fig. 4. SSLS reliability vs. the number of components, assuming one failure mode (top-down V' = 1.5, 2, 3, 4).

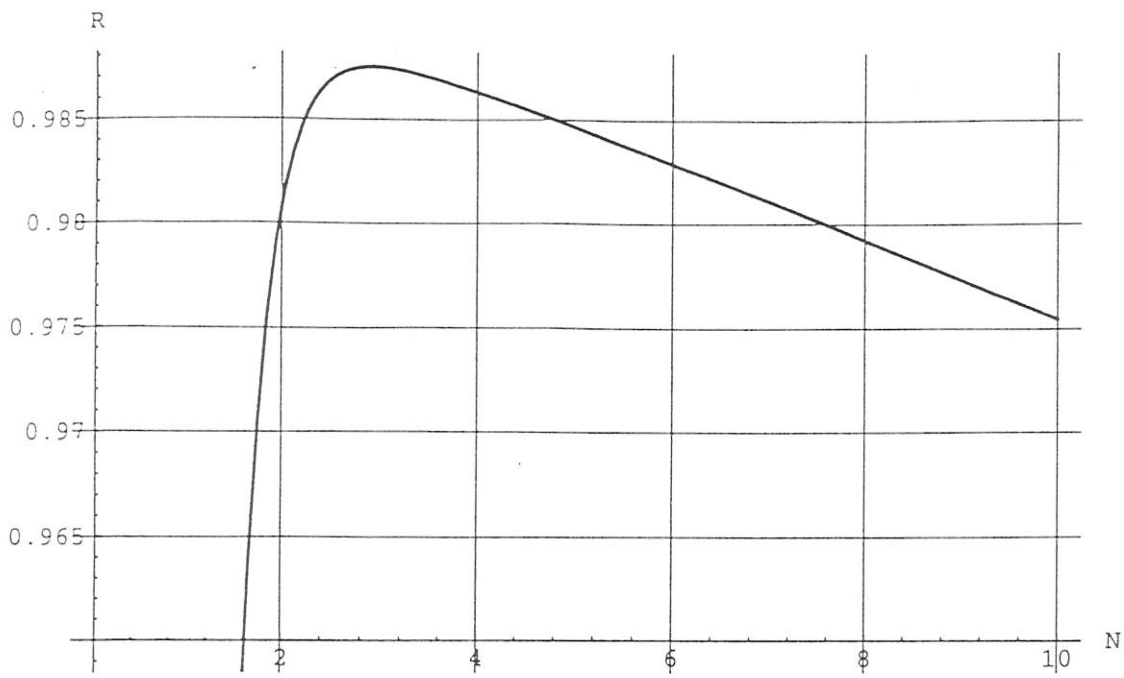

Fig. 5. SSLS reliability vs. the number of components, assuming two failure modes (V' = 1).

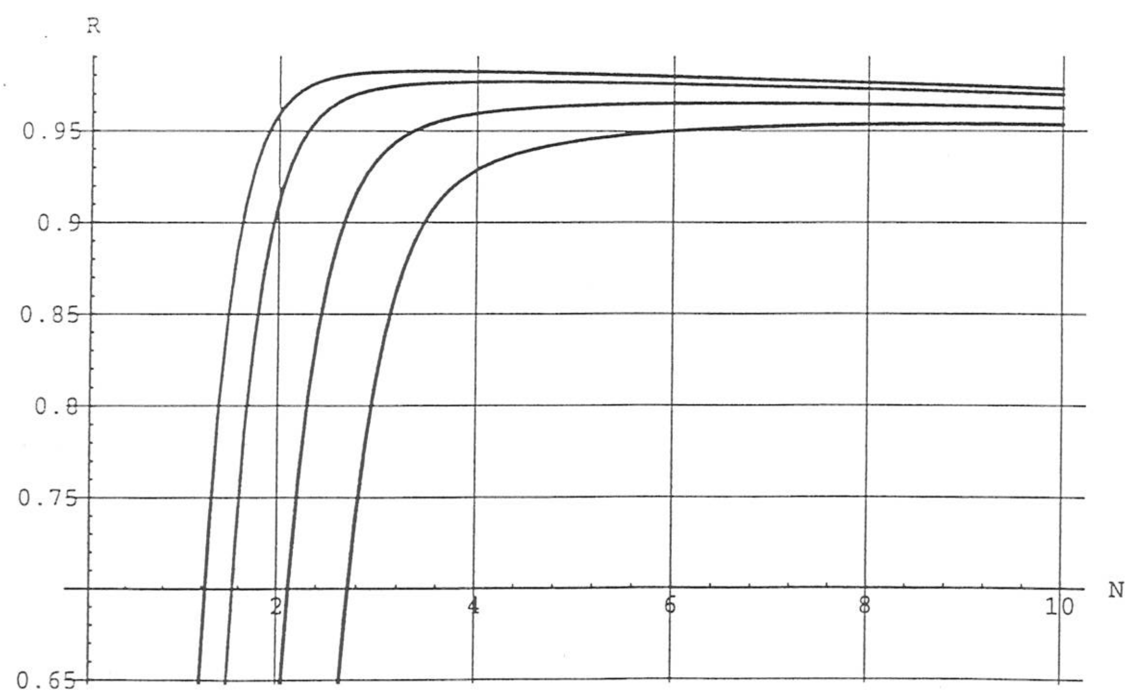

Fig. 6. SSLS reliability vs. the number of components, assuming two failure modes (top-down V' = 1.5, 2, 3, 4).